IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: David A. Waldman, et al.	Attorney Docket No.: VISGP001
Application No.: 10/561,646	Examiner: Unknown
Filed: December 20, 2005	Group: Unknown

Title: ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES

CERTIFICATE OF MAILING

I hereby certify that this correspondence is being deposited with the U.S. Postal Service with sufficient postage as first-class mail on October 12, 2006 in an envelope addressed to the Commissioner for Patents, P.O. Box 1450 Alexandria, VA 22313-1450.

Signed: _____
Valerie Olsen

PETITION FOR APPLICATION BY OTHER THAN ALL THE INVENTORS
Pursuant to 37 C.F.R. §1.47 (a)

Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

Applicants **David A. Waldman, Richard T. Ingwall, Daniel H. Raguin, John S. Berg, Joby Joseph, and David L. Kent** (the "remaining joint inventors") hereby petition the Commissioner to accept for application the above-identified U.S. Patent Application by other than all of the inventors.

The Declaration For Patent Application is attached in which the remaining joint inventors have signed on behalf of the omitted inventors as required by 37 C.F.R. §1.64 and M.P.E.P. §409.03(a), and it includes the last known address of the omitted inventor.

A Declaration of Facts in Support of Applying on Behalf of the Omitted Inventor is also attached and provides proof of the pertinent facts regarding the omitted inventor who refuses to sign as required by 37 C.F.R. §1.47(a) and M.P.E.P. §409.03(d).

In view of the refusal of the omitted inventor to sign the papers required for the above-identified application, the remaining joint inventors are believed to be entitled to make such an

10/18/2006 MKAYPAGH 00000102 10561646
03 FC:1463 200.00 OP

application on behalf of and as agents for the omitted inventor. The required fee pursuant to 37 C.F.R. §1.17(g) is enclosed.

Dated: 10/12/06

Respectfully submitted,
BEYER WEAVER & THOMAS, LLP

William J. Egan, III
Registration No. 28,411

P.O. Box 70250
Oakland, CA 94612-0250

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In re application of: David A. Waldman, et al.	Attorney Docket No.: VISGP001
Application No.: 10/561,646	Examiner: Unknown
Filed: December 20, 2005	Group: Unknown
Title: ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES	

DECLARATION OF FACTS IN SUPPORT OF APPLYING ON BEHALF OF OMITTED INVENTOR
Pursuant to 37 C.F.R. §1.47 (a)

Commissioner of Patents
P.O. Box 1450
Alexandria, VA 22313-1450

Dear Sir:

This declaration is made as to the facts that are relied upon to establish the diligent effort made to secure the execution of the Declaration for the subject U.S. application by the omitted inventor, Vincent Fedele. This declaration is being made by the available person having first-hand knowledge of the facts recited therein.

I, William J. Egan, III, do hereby declare:

1. The subject U.S. application is based on a Patent Cooperation Treaty (PCT) application flied on June 21, 2004 and having International Application No. PCT/US2004/019917.

2. All rights in and throughout the United States of America, its territories, and all foreign countries, in and to the invention described in the subject PCT application were assigned to Aprilis, Inc. ("Aprilis"). An Assignment was executed by all the inventors, including Vincent Fedele, and is was recorded in the U.S. Patent and Trademark Office (PTO). See attached Exhibit A.

3. After receiving a "Notification Of Missing Requirements Under 35 U.S.C. 371 In The United States Designated/Elected Office (DO/EO/US)", the prior law firm representing Aprilis, Hamilton, Brook, Smith & Reynolds, P.C., forwarded, on March 6, 2006, a Declaration For Patent Application ("Declaration") to Mr. David A. Waldman at Aprilis for execution by all the inventors. See attached Exhibit B.

4. This Declaration was executed by all the inventors, except for Vincent Fedele. Apparently, prior to the time the Declaration was sent to Aprilis, Vincent Fedele had left Aprilis.

5. Some time in July 2006, responsibility for the subject U.S. application was transferred from Hamilton, Brook, Smith & Reynolds, P.C. to Beyer, Weaver & Thomas LLP.

6. On July 20, 2006, I sent a copy of the PCT application along with a Declaration and Assignment to Vincent Fedele at his last known address. These documents were sent via Certified Mail, Return Receipt Requested. I asked that Mr. Fedele return the executed Declaration and Assignment by August 18, 2006. See attached Exhibit C.

7. Subsequently, some time around August 3, 2006, I received a letter from Vincent Fedele dated July 27, 2006. By this letter, Vincent Fedele indicated that he would not sign the Declaration and Assignment nor review the application sent to him by my letter of July 20, 2006, unless he received compensation from Aprilis. See attached Exhibit D.

8. On August 24, 2006, I received from Vincent Fedele, the entire package that I had forwarded to him by my letter of July 20, 2006. This package was sent back to me with the letter from Vincent Fedele dated July 27, 2006. See attached Exhibit E.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code, and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

William J. Egan, III

10/12/06

Date

FAX

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From:
Name: USPTO ASSIGNMENT DIVISION
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1	Cover Page
2	759.TXT
4	Document 1, Batch 443777

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TIMOTHY J. MEAGHER
HAMILTON BROOK SMITH, ET AL.
530 VIRGINIA ROAD
P.O. BOX 9133
CONCORD, MA 01742-0136

UNITED STATES PATENT AND TRADEMARK OFFICE
NOTICE OF RECORDATION OF ASSIGNMENT DOCUMENT

THE ENCLOSED DOCUMENT HAS BEEN RECORDED BY THE ASSIGNMENT DIVISION OF THE U.S. PATENT AND TRADEMARK OFFICE. A COMPLETE MICROFILM COPY IS AVAILABLE AT THE ASSIGNMENT SEARCH ROOM ON THE REEL AND FRAME NUMBER REFERENCED BELOW.

PLEASE REVIEW ALL INFORMATION CONTAINED ON THIS NOTICE. THE INFORMATION CONTAINED ON THIS RECORDATION NOTICE REFLECTS THE DATA PRESENT IN THE PATENT AND TRADEMARK ASSIGNMENT SYSTEM. IF YOU SHOULD FIND ANY ERRORS OR HAVE QUESTIONS CONCERNING THIS NOTICE, YOU MAY CONTACT THE EMPLOYEE WHOSE NAME APPEARS ON THIS NOTICE AT 703-308-9723. PLEASE SEND REQUEST FOR CORRECTION TO: U.S. PATENT AND TRADEMARK OFFICE, MAIL STOP: ASSIGNMENT SERVICES DIVISION, P.O. BOX 1450, ALEXANDRIA, VA 22314.

RECORDATION DATE: 03/31/2005

REEL/FRAME: 015987/0654
NUMBER OF PAGES: 12

BRIEF: ASSIGNMENT OF ASSIGNOR'S INTEREST (SEE DOCUMENT FOR DETAILS).

ASSIGNOR:
WALDMAN, DAVID A. DOC DATE: 12/08/2004

ASSIGNOR:
FEDELE, VINCENT DOC DATE: 12/20/2004

ASSIGNOR:
INGWALL, RICHARD T. DOC DATE: 03/08/2005

ASSIGNOR:
RAGUIN, DANIEL H. DOC DATE: 12/17/2004

ASSIGNOR:
BERG, JOHN S. DOC DATE: 12/17/2004

ASSIGNOR:
JOSEPH, JOBY DOC DATE: 11/04/2004

ASSIGNOR:
KENT, DAVID L.

DOC DATE: 12/08/2004

ASSIGNEE:
APRILIS, INC.
5 CLOCK TOWER PLACE
SUITE 200
MAYNARD, MASSACHUSETTS 01754

SERIAL NUMBER:
PATENT NUMBER:
PCT NUMBER: US0419917

FILING DATE: 06/21/2004
ISSUE DATE:

TITLE: ACQUISTION OF HIGH RESOLUTION BIOMETRIC IMAGES

STEVEN POST, EXAMINER
ASSIGNMENT DIVISION
OFFICE OF PUBLIC RECORDS

RECORDATION FORM COVER SHEET
PATENTS ONLY

Docket No.: 3174.1012-004 PCT

To the Director of the U.S. Patent and Trademark Office: Please record the attached documents or the new address(es) below.

1. Name of conveying party(ies)/Execution Date(s).

DAVID A. WALDMAN — JOHN S. BERG
VINCENT FEDELE — JOBY JOSEPH
RICHARD T. INGWALL — DAVID L. KENT
DANIEL H. RAGUIN

Execution Date: 12-08-04; 12-20-04; 03-08-05; 12-17-04; 12-17-04; 11-04-04; 12-08-04

Additional name(s) of conveying party(ies) attached? [ ] Yes [X] No

2. Name and address of receiving party(ies)

Name: APRILIS, INC.

Internal Address:

Street Address: 5 CLOCK TOWER PLACE; SUITE 200

City: MAYNARD

State: MA

Country: USA Zip: 01754

Additional name(s) & address(es) attached? [ ] Yes [X] No

3. Nature of conveyance.

[X] Assignment [ ] Merger

[ ] Security Agreement [ ] Change of Name

[ ] Other

4. Application number(s) or patent number(s):

[ ] This document is being filed together with a new application.

A. Patent Application No.(s)
PCT/US2004/019917

B. Patent No.(s)

Additional numbers attached? [ ] Yes [X] No

5. Name and address of party to whom correspondence concerning document should be mailed.

Name: TIMOTHY J. MEAGHER

Internal Address:

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.

Street Address: 530 VIRGINIA ROAD, P.O. BOX 9133

City: CONCORD State: MA ZIP: 01742-9133

Phone No.: 978-341-0036 Fax No: 978-341-0136

Email Address: TIM.MEAGHER@HBSR.COM

6. Total number of applications and patents involved: [1]

7. Total Fee (37 C.F.R. 3.41)..... $ 40.00

[ ] Enclosed

[X] Authorization to charge deposit account number 08-0380

[ ] Previously submitted - Doc ID No [ ]

[X] Authorized to charge any deficiencies or credit any overpayment to deposit account number 08-0380

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8. Alexander Akhiezer
Name of Person Signing

Alexander Akhiezer
Signature

3/8/05
Date

Total number of pages including cover sheet, attachments, and document: [11]

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.
0 Virginia Road, P.O. Box 9133
Concord, MA 01742-9133

Telephone: (978) 341-0036 Facsimile: (978) 341-0136

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FACSIMILE COVER SHEET

Examiner: **Assignment Division**
U.S. Patent and Trademark Office

Date: March 31, 2005

Client Code: 3174

Facsimile No.: 703-306-5995

From: Alexander Akhiezer, Ph.D.

Subject:

Paper:	Assignment Recordation
Docket No.:	3174.1012-004 PCT
Applicant:	David A. Waldman, et al.
Application No.:	PCT/US2004/019917
Filing Date:	June 21, 2004

Number of pages including this cover sheet: 12

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Time : Mar-31-05 02:36pm
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Date : Mar-31 02:32pm

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Document Pages : 12

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530 Virginia Road, P.O. Box 9133
Concord, MA 01742-9133
Telephone: (978) 341-0036 Facsimile: (978) 341-0136

FACSIMILE COVER SHEET

Examiner: Assignment Division
U.S. Patent and Trademark Office

Date: March 31, 2005

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Facsimile No.: 703-306-5995

From: Alexander Akhiezer, Ph.D.

Subject:
Paper: Assignment Recordation
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Applicant: David A. Waldman, et al.
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Number of pages including this cover sheet: 12

Please confirm receipt of facsimile: Yes X No ____

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RECORDATION FORM COVER SHEET
PATENTS ONLY

Docket No.: 3174.1012-004 PCT

To the Director of the U.S. Patent and Trademark Office: Please record the attached documents or the new address(es) below.

1. Name of conveying party(ies)/Execution Date(s):

DAVID A. WALDMAN JOHN S. BERG
VINCENT FEDELE JOBY JOSEPH
RICHARD T. INGWALL DAVID L. KENT
DANIEL H. RAGUIN

Execution Date: 12-08-04; 12-20-04; 03-08-05; 12-17-04; 12-17-04; 11-04-04; 12-08-04

Additional name(s) of conveying party(ies) attached? [ ] Yes [X] No

2. Name and address of receiving party(ies)

Name: APRILIS, INC.

Internal Address:

Street Address: 5 CLOCK TOWER PLACE; SUITE 200

City: MAYNARD

State: MA

Country: USA Zip: 01754

Additional name(s) & address(es) attached? [ ] Yes [X] No

3. Nature of conveyance:

[X] Assignment [ ] Merger

[ ] Security Agreement [ ] Change of Name

[ ] Other

4. Application number(s) or patent number(s):

[ ] This document is being filed together with a new application.

A. Patent Application No.(s)
PCT/US2004/019917

B. Patent No.(s)

Additional numbers attached? [ ] Yes [X] No

5. Name and address of party to whom correspondence concerning document should be mailed:

Name: TIMOTHY J. MEAGHER

Internal Address:

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.

Street Address: 530 VIRGINIA ROAD, P.O. BOX 9133

City: CONCORD State: MA ZIP: 01742-9133

Phone No. 978-341-0036 Fax No. 978-341-0136

Email Address: TIM.MEAGHER@HBSR.COM

6. Total number of applications and patents involved: [1]

7. Total Fee (37 C.F.R. 3.41)..... $ 40.00

[ ] Enclosed

[X] Authorization to charge deposit account number 08-0380

[ ] Previously submitted - Doc. ID No. [ ]

[X] Authorized to charge any deficiencies or credit any overpayment to deposit account number 08-0380

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8. Alexander Akhiezer
Name of Person Signing

Alexander Akhiezer
Signature

3/31/05
Date

Total number of pages including cover sheet, attachments, and document: [11]

Docket No. 3174.1012-004 PCT

Joint

ASSIGNMENT

WHEREAS, we, **David A. Waldman, Vincent Fedele, Richard T. Ingwall, Daniel H. Raguin, John S. Berg, Joby Joseph and David L. Kent**, have invented a certain improvement in **ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019917**, filed **June 21, 2004**;

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, MA 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the

execution of applications for patents in foreign countries, and the execution of any future applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: _____

David A. Waldman

State/Commonwealth

of Massachusetts

County of Middlesex

On this 8 day of December, 2004, before me, the undersigned notary public, personally appeared **David A. Waldman**,

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA Driver License

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

Frances French (print name)

My Commission expires ____/____/____

Frances French
NOTARY PUBLIC
My commission expires Dec. 4, 2009

Inventor's Signature: /V Fedele

Vincent Fedele

State/Commonwealth

of Massachusetts

County of Worcester Middlesex

On this 20 day of December, 2004, before me, the undersigned notary public, personally appeared **Vincent Fedele,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA Dr Lic Exp 1-24-08

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) Colleen Beliveau Notary Public

Colleen Beliveau (print name) Colleen A. Beliveau NOTARY PUBLIC My commission expires Sept. 25, 2009

My Commission expires ____/____/____

Inventor's Signature: _____

Richard T. Ingwall

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Richard T. Ingwall,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____

Daniel H. Raguin

State/Commonwealth
of Massachusetts
County of Middlesex

On this 17th day of December, 2004, before me, the undersigned notary public, personally appeared **Daniel H. Raguin,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA Driver's License

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

Linda L. Cetrone (print name)

My Commission expires 03/03/06.

LINDA L. CETRONE
Notary Public
My Commission Expires
March 3, 2006

Inventor's Signature: _____

John S. Berg

State/Commonwealth
of Massachusetts
County of Middlesex

On this 17th day of December, 2004, before me, the undersigned notary public, personally appeared **John S. Berg,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was USA Passport

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

Linda L. Cetrone (print name)

My Commission expires 3/03/06

LINDA L. CETRONE
Notary Public
My Commission Expires

Docket No. 3174.1012-004 PCT

Inventor's Signature: _____
Joby Joseph

State/Commonwealth
of _____
County of _____

34 Vaishali Apartments
I.I.T. Delhi
New Delhi 110016
India

On this 4 day of November, 2004, before me, the undersigned notary public, personally appeared **Joby Joseph,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was Passport of Republic of India, No. A4564059

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) VALID FOR INDIA ATTESTED - 4 NOV 2004 NOTARY PUBLIC DELHI (INDIA) _____ Notary Public

S. P. SINGH (print name)

My Commission expires 23/2/2007

The Seal of Notary Public App. by Govt. of N.C.T. of Delhi S. P. SINGH

Inventor's Signature: _____
David L. Kent

State/Commonwealth
of Massachusetts
County of Middlesex

On this 8 day of December, 2004, before me, the undersigned notary public, personally appeared **David L. Kent,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA Driver License

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

FRANCES French (print name)

My Commission expires ____/____/____

Frances French NOTARY PUBLIC My commission expires Dec. 4, 2009

Joint

ASSIGNMENT

WHEREAS, we, **David A. Waldman, Vincent Fedele, Richard T. Ingwall, Daniel H. Raguin, John S. Berg, Joby Joseph and David L. Kent**, have invented a certain improvement in **ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019917**, filed **June 21, 2004;**

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, MA 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the

execution of applications for patents in foreign countries, and the execution of any future applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: _____

David A. Waldman

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **David A. Waldman,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Docket No. 3174.1012-004 PCT

Inventor's Signature: Vincent Fedele

Vincent Fedele

State/Commonwealth
of Massachusetts
County of Worcester Middlesex

On this 20 day of December, 2004, before me, the undersigned notary public, personally appeared **Vincent Fedele,**

☐ personally known to me, or

☑ proved to me through satisfactory evidence of identification, which was MA Dr Lic Exp 1-24-08

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) Colleen Beliveau Notary Public

Colleen Beliveau (print name) Colleen A. Beliveau NOTARY PUBLIC My commission expires Sept. 25, 2009

My Commission expires / /

Inventor's Signature: Richard T Ingwall

Richard T. Ingwall

State/Commonwealth
of CALIFORNIA
County of SAN DIEGO

On this 8TH day of MARCH, 2005, before me, the undersigned notary public, personally appeared **Richard T. Ingwall,**

☐ personally known to me, or

☒ proved to me through satisfactory evidence of identification, which was MASSACHUSETTS DRIVERS LICENSE # S45456104 EXP. 4/13/07

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

SILVIA B. VASQUEZ Commission # 1388775 Notary Public - California San Diego County My Comm. Expires Dec 18, 2006

(SEAL) Silvia B Vasquez Notary Public

SILVIA B. VASQUEZ (print name)

My Commission expires 12/18/2006

Inventor's Signature: _____

Daniel H. Raguin

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Daniel H. Raguin,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

John S. Berg

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **John S. Berg,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: ______________________________
Joby Joseph

State/Commonwealth

of ______________________

County of ______________________

On this __________ day of ________________, 20_____, before me, the undersigned notary public, personally appeared **Joby Joseph**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was ______________________________

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) ______________________ Notary Public

______________________ (print name)

My Commission expires ____/____/____

Inventor's Signature: ______________________________
David L. Kent

State/Commonwealth

of ______________________

County of ______________________

On this __________ day of ________________, 20_____, before me, the undersigned notary public, personally appeared **David L. Kent**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was ______________________________

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) ______________________ Notary Public

______________________ (print name)

My Commission expires ____/____/____

HAMILTON
BROOK
SMITH &
REYNOLDS, P.C.

PATENTS, TRADEMARKS
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530 VIRGINIA ROAD
P.O. BOX 9133
CONCORD, MA 01742-9133
TEL (978) 341-0036
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www.hbsr.com

March 6, 2006

David A. Waldman, Ph.D.
Vice President, Research and Development
Aprilis, Inc.
5 Clock Tower Place
Suite 200
Maynard, Massachusetts 01754

Re: U.S. National Stage Application No.: 10/561,646
Title: "Acquisition of High Resolution Biometric Images"
HBSR Docket No.: 3174.1012-013

Dear David:

Enclosed is a Declaration for Patent Application for the referenced case and an Assignment form in which each inventor assigns rights to the invention to **Aprilis, Inc**.

It is appropriate at this time to confirm that we have designated the correct inventor(s) in the attached Declaration and that the specification and claims meet the enablement and best mode requirements under U.S. patent law.

To assist you in this determination, each inventor should note the following:

1. Inventorship: Only persons who have made an inventive contribution to the conception of at least one of the claims in the patent application should be listed as an inventor. Any doubts on this matter should be resolved with me before proceeding further.

2. Enablement: This requirement imposes an obligation on the inventor to describe the invention in sufficient detail to enable a person skilled in the art to make and use the invention

which is the subject of the patent application without undue experimentation.

3. Best Mode: The "best mode" requirement goes further than the "enablement" requirement by obligating the inventor to include in the patent application a description of the best mode contemplated by the inventor of practicing the invention.

An inventor's failure to comply with the "best mode" or "enablement" requirements may invalidate a patent. In addition, intentional failure to correctly name inventors could result in an invalid or unenforceable patent. If you have any questions or concerns, please call me.

Please note that the Declaration requires that each inventor carefully read the patent application in its entirety before signing it. If the application is acceptable, please have each inventor sign the Declaration in BLUE ink. Each inventor should also check to be sure that the typed name, address and citizenship on the Declaration are correct. If they are not, the inventor should indicate the correct information in BLUE ink, and initial and date each correction in the margin.

If you have any questions or concerns, or feel any changes need to be made in the Declaration, please call me.

The Assignment should be signed in BLUE ink by each inventor in the presence of a Notary Public.

Please return **all** pages of these documents as soon as possible for filing in the U.S. Patent and Trademark Office.

Very truly yours,

HAMILTON, BROOK, SMITH & REYNOLDS, P.C.

By Alexander Akhiezer
Alexander Akhiezer

AA/saj
Enclosures

cc: Timothy J. Meagher, Esq.

BEYER WEAVER & THOMAS, LLP

INTELLECTUAL PROPERTY LAW

500 12th Street, Suite 200, Oakland, CA 94607
Telephone: (510) 663-1100 Facsimile: (510) 663-0920
www.beyerlaw.com

July 20, 2006

VIA CERTIFIED MAIL, RETURN RECEIPT REQUESTED

Mr. Vincent Fedele
P.O. Box 061
Harvard, MA 01451

Re: U.S. Patent Application Entitled: ***"Acquisition Of High Resolution Biometric Images"***
Inventors: David A. Waldman, et al.
Filing Date: December 20, 2005
Our File: VISGP001

Dear Mr. Fedele:

We represent Aprilis, Inc.

Enclosed is a copy of the above-identified patent application as filed with the U.S. Patent and Trademark Office. You may recall that the application was filed without having you sign the necessary documents (declaration and assignment forms) which should to be filed with the U.S. Patent and Trademark Office by **August 22, 2006** in order to avoid abandonment of the application.

Accordingly, we are enclosing two documents (i) a Declaration (ii) an Assignment of rights to Aprilis, Inc. Before executing these documents, please ensure that you have reviewed and understand the contents of the patent application. Then, read, sign and date each of the enclosed documents adjacent to where your name appears, and return them to our office, in the enclosed, self-addressed stamped envelope, **by August 18, 2006,** so that we may file them with the U.S. Patent and Trademark Office. Also, please note that your signature on the Assignment should be notarized.

Finally, we would again like to remind you of our duty to disclose the most pertinent prior art of which you are aware to the Patent and Trademark Office. If you can think of any pertinent references or patents, or any similar existing technology, please let us know. The duty to disclose prior art continues until the patent actually issues. As such, if you become aware of other prior art in the future, please let us know.

If you have any questions, please call.

Best regards,
BEYER WEAVER & THOMAS, LLP

William J. Egan, III

Enclosures

7006 0100 0001 5825 2995

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DOCKET NO. 3174.1012-013

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Declaration for Patent Application

[ ] Supplemental (37 C.F.R. §1.67)

As a named inventor, I hereby declare that:

My residence, mailing address and citizenship are as stated next to my name;

I believe I am the original, first and sole inventor (if only one name is listed) or an original, first and joint inventor (if plural names are listed in the signatory page(s) commencing at page 2 hereof) of the subject matter which is claimed and for which a patent is sought on the invention entitled

ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES

the specification of which (check one)

[ ] is attached hereto.

[ ] was filed on [ ] as United States Application Number [ ].

[X] was filed on June 21, 2004 as PCT International Application No. PCT/US2004/019917 and assigned United States Application No. 10/561,646.

[ ] and was amended on [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. §1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application.

I hereby claim foreign priority benefits under 35 U.S.C. 119 or 365 of any foreign application(s) for patent or inventor's certificate, or of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Not Claimed	Certified Copy Filed? YES	NO
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of **sole** or **first** inventor: David A. Waldman

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Concord	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: 31 Mitchell Road

City	State	ZIP	Country
Concord	MA	01742	USA

Full name of **second** joint inventor, if any: Vincent Fedele

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Harvard	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: P.O. Box 061

City	State	ZIP	Country
Harvard	MA	01451	USA

Full name of **third** joint inventor, if any: Richard T. Ingwall

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Newton	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: 115 Dartmouth Street

City	State	ZIP	Country
Newton	MA	02465	USA

Full name of **fourth** joint inventor, if any: Daniel H. Raguin

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Acton	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: 234 Newtown Road

City	State	ZIP	Country
Acton	MA	01720	USA

Full name of **fifth** joint inventor, if any John S. Berg

Inventor's Signature

Residence: City	State	Country	Citizenship
Franklin	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box 58 Jefferson Road

City	State	ZIP	Country
Franklin	MA	02038-3360	USA

Full name of **sixth** joint inventor, if any Joby Joseph

Inventor's Signature

Residence: City	State	Country	Citizenship
New Delhi		India	India

Mailing Address (Business or Residential)
Street or P.O. Box 34 Vaishali Apt., I.I.T. Delhi

City	State	ZIP	Country
New Delhi		110016	India

Full name of **seventh** joint inventor, if any David L. Kent

Inventor's Signature

Residence: City	State	Country	Citizenship
Framingham	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box 10 Frost Street

City	State	ZIP	Country
Framingham	MA	01701	USA

Docket No. 3174.1012-013

Joint

ASSIGNMENT

WHEREAS, we, **David A. Waldman, Vincent Fedele, Richard T. Ingwall, Daniel H. Raguin, John S. Berg, Joby Joseph and David L. Kent,** have invented a certain improvement in **ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019917**, filed **June 21, 2004**, which designates the United States of America and assigned United States Application No. **10/561,646**;

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, Massachusetts 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein; I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the execution of applications for patents in foreign countries, and the execution of any future applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: _____

David A. Waldman

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **David A. Waldman,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____

Vincent Fedele

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Vincent Fedele,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____

Richard T. Ingwall

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Richard T. Ingwall,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____

Daniel H. Raguin

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **Daniel H. Raguin,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____ **John S. Berg**

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20____, before me, the undersigned notary public, personally appeared **John S. Berg,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires ____/____/____

Inventor's Signature: _____

Joby Joseph

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Joby Joseph,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

David L. Kent

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **David L. Kent,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

WO 2005/001753
PCT/US2004/01991

SAW

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION CONCERNING TRANSMITTAL OF COPY OF INTERNATIONAL APPLICATION AS PUBLISHED OR REPUBLISHED

To:

MEAGHER, Timothy, J.
Hamilton, Brook, Smith & Reynolds, P.C.
530 Virginia Road
P.O. Box 9133
Concord, MA 01742-9133
ETATS-UNIS D'AMERIQUE

Date of mailing *(day/month/year)* 06 January 2005 (06.01.2005)	
Applicant's or agent's file reference 3174.1012004	**IMPORTANT NOTICE**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US2004/019917	21 June 2004 (21.06.2004)	21 June 2003 (21.06.2003)

Applicant

APRILIS, INC. et al

The International Bureau transmits herewith the following documents:

☑ copy of the international application as published by the International Bureau on 06 January 2005 (06.01.2005) under No. WO 2005/001753

☐ copy of international application as republished by the International Bureau on under No. WO

For an explanation as to the reason for this republication of the international application, reference is made to INID codes (15), (48) or (88) (*as the case may be*) on the front page of the attached document.

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer Simin Baharlou
Facsimile No.+41 22 740 14 35	Facsimile No.+41 22 338 71 30

Form PCT/IB/311 (January 2004)

3174.1012-004

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 January 2005 (06.01.2005)

PCT

(10) International Publication Number
WO 2005/001753 A1

(51) International Patent Classification[7]: G06K 9/00

(21) International Application Number:
PCT/US2004/019917

(22) International Filing Date: 21 June 2004 (21.06.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/480,008	21 June 2003 (21.06.2003)	US
60/519,792	13 November 2003 (13.11.2003)	US
60/523,068	18 November 2003 (18.11.2003)	US

(71) Applicant *(for all designated States except US)*: APRILIS, INC. [US/US]; 5 Clock Tower Place, Suite 200, Maynard, MA 01754 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: WALDMAN, David [US/US]; 31 Mitchell Road, Concord, MA 01742 (US). FEDELE, Vincent [US/US]; Post Office Box 061, Harvard, MA 01451 (US). INGWALL, Richard, T. [US/US]; 115 Dartmouth Street, Newton, MA 02465 (US). RAGUIN, Daniel, H. [US/US]; 234 Newtown Road, Acton, MA 01720 (US). BERG, John, S. [US/US]; 58 Jefferson Road, Franklin, MA 02038 (US). JOSEPH, Joby [IN/US]; Waltham, MA 02453 (US). KENT, David, L. [US/US]; 10 Frost Street, Framingham, MA 01701 (US).

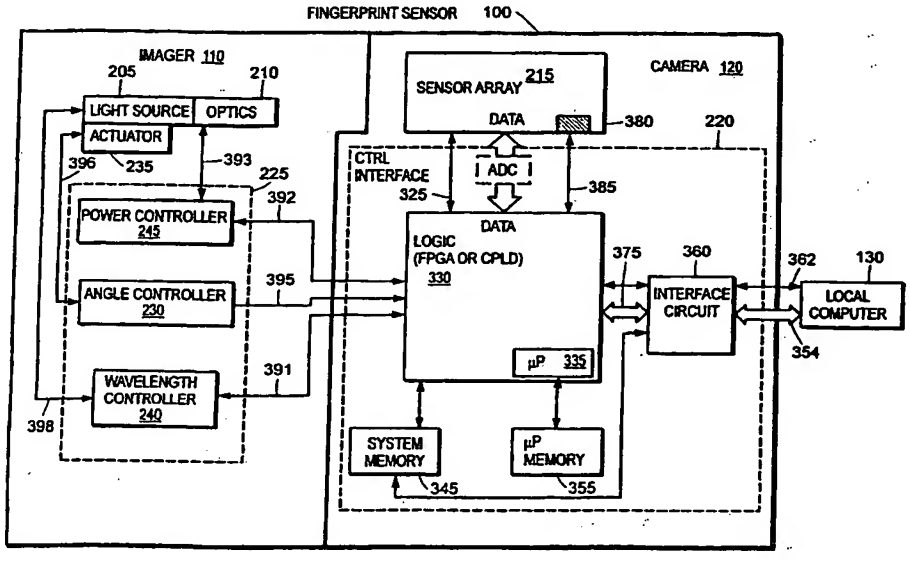
(74) Agents: MEAGHER, Timothy, J. et al.; Hamilton, Brook, Smith & Reynolds, P.C., 530 Virginia Road, P.O. Box 9133, Concord, MA 01742-9133 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

[Continued on next page]

(54) Title: ACQUISITION OF HIGH RESOLUTION BOIMETRIC IMAGES



(57) Abstract: An apparatus for image acquisition of topological features of the surface of skin. The apparatus comprises a waveguide, having an entrance edge and top and bottom surfaces; a light source, configured to direct a light beam at the entrance edge of the waveguide; a skin contact layer, disposed at or near the top surface of the waveguides; a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer; a sensor array, configured to detect light reflected from the surface of skin in contact with skin contact layer; and means for compensating for changes in the Bragg matching condition of the HOE due to temperature.

WO 2005/001753 A1

ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/480,008, filed on June 21, 2003, U.S. Provisional Application No. 60/519,792, filed on November 13, 2003 and U.S. Provisional Application No. 60/523,068, filed on November 11, 2003. This application is related to the PCT Application entitled "Method and Apparatus for Processing Biometric Images" filed concurrently herewith on June 21, 2004 under the attorney docket number 3174.1012-006. The entire teachings of the above applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Growing concerns regarding domestic security have created a critical need to positively identify individuals as legitimate holders of credit cards, driver's licenses, passports and other forms of identification. The ideal identification process is reliable, fast, and relatively inexpensive. It should be based on modern high-speed electronic devices that can be networked to enable fast and effective sharing of information. It should also be compact, portable, and robust for convenient use in a variety of environments, including airport security stations, customs and border crossings, police vehicles, home and office computing and entrance control sites of secure buildings.

A well established method for identification is to compare a fingerprint with a previously obtained authentic fingerprint of the individual. Fingerprints have traditionally been collected by rolling an inked finger on a white paper. Since this traditional process clearly fails to meet the criteria listed above, numerous attempts have been made to adapt an electronically imaged fingerprint method to address new security demands. These modern proposals all use, as a key component, a solid-state device such as a capacitive or optical sensor to capture the fingerprint image in a digital format. By using a new type of solid-state imager as part of a fingerprint

with a few minutiae points can positively identify an individual reliably.

Most optical designs proposed for creating fingerprint images suffer important limitations that reduce their usefulness in real life applications. Many designs are not suitable, for example, to resolve pore patterns or fine detail of the contour of the intersection of ridges and valleys in the fingerprint. Other designs produce distorted images that complicate fingerprint correlation, and still other designs are too bulky or delicate for convenient use in the field.

One optical design that reduces the overall size of the device uses holograms to diffract light in a desired direction. A common limitation of such devices is sensitivity of the intensity of illumination of the target topological surface to variation in temperature with respect to angle and wavelength of the incident light. Accordingly, there is a need for a compact, high resolution device that reliably operates over a broad range of temperature.

SUMMARY OF THE INVENTION

The present invention relates to an apparatus and method of acquisition of an image of any surface topology present on skin, which, by way of example, can be a rolled and/or slap fingerprint, palm print, etc. and hereinafter for convenience will be referred to as a fingerprint.

In one embodiment, the present invention is an apparatus for fingerprint image acquisition, comprising a waveguide, having an entrance edge and top and bottom; a light source, configured to direct a light beam at the entrance edge of the waveguide; a skin contact layer, disposed at or near the top surface of the waveguide or bottom surface of the waveguide; a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer; a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer. The HOE includes a layer comprising a grating and at least one supporting layer in contact with the said grating layer, wherein the grating layer and the at least one supporting layer have substantially similar coefficients of thermal expansion or thermo-optic coefficients or both.

light beam at the entrance edge of the waveguide; a skin contact layer, disposed at the top surface of the waveguide; a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam at the skin contact layer and having a Bragg matching condition; a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer, and means for compensating for changes in the Bragg matching condition of the HOE due to changes in temperature. The light source is a broad wavelength spectrum light source, the wavelengths of which can reconstruct the HOE.

In one embodiment, the present invention is a method of acquiring an image of the topology of the surface of skin, comprising receiving a surface of skin by a device for image acquisition of the topological features of the surface of skin wherein said device includes a holographic optical element (HOE) having a Bragg matching condition; directing a light beam at the HOE, thereby diffracting the light beam; directing the diffracted light beam at the interface between skin and the skin contact layer, thereby reflecting the light beam; compensating for temperature-induced changes in the Bragg matching condition of the HOE; and detecting the reflected light, thereby acquiring the image of the topological features of the surface of skin by said device.

It should be understood that the example embodiments described above, include a corresponding method or apparatus embodiments.

The device of the present invention is preferably compact, possesses a broad operating temperature range and advantageously allows the acquisition of images that capture pore structural features and fine detail features of the contour of the ridge structure in addition to standard minutiae structures. We have shown that the use of pores combined with the use of the fine detail of the ridge contour and the usual minutiae significantly increases the reliability of fingerprint comparisons, and substantially reduces the false accept rate, as well as providing positive identification with use of fingerprint sample areas as small as 0.1 x 0.1 inches.

Various example embodiments of the instrument used to acquire images of biometrics are described herein. The embodiments may also include alternative embodiments of the instrument and various embodiments of acquiring, modeling,

DETAILED DESCRIPTION OF THE INVENTION

A description of preferred embodiments of the invention for a fingerprint biometric follows. It should be understood that the principles of the present invention and example preferred embodiments of the methods and apparatus described below may be applied to other biometrics, including: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, fingerprints, palm prints, foot prints, toe prints, or prints of other areas of the skin, including hair.

FIG. 1 is a system diagram in which an embodiment of a fingerprint sensor according to the principles of the present invention is employed. The fingerprint sensor 100 includes a fingerprint imager 110 and fingerprint camera 120. The imager 110 and camera 120 may be mechanically, electrically, and optically connected in a single "box." A finger 105 or other topological surface of skin is placed on the fingerprint imager 110 at a "viewable" location by the imager 110 for acquisition of a fingerprint or information of other topological surfaces of skin 115 by the camera 120 and for modeling of the fingerprint 115 by processing as described in co-pending PCT application with attorney docket number 3174.1012-006 filed concurrently herewith on June 21, 2004.

Continuing to refer to FIG. 1, the fingerprint camera 120 includes an interface to communicate bidirectionally with a local computer 130 via a control channel/data link 125. The fingerprint camera 120 sends image data 160 to the local computer 130, and the local computer 130 may send control data 165 or other information, including image data 125, to the fingerprint camera 120 or imager 110 via the link 125.

The local computer 130 includes a variety of processing capabilities, such as modeling, authentication, and authorization that are applied to the image data 160. The local computer 130 is in communication with a local database 135 via a local link 132. Image data and associated model(s) 170, collectively, are communicated between the local computer 130 and local database 135 via the local link 132. Other data, such as administrative data, may also be communicated over the local link 132 for storage in the local database 135 for later retrieval.

that are available with fully proportional-integral-derivative feedback for closed loop control (second wavelength adsorber within HOE).

FIG. 2 is a hierarchical diagram of the fingerprint sensor 100. The fingerprint sensor 100, as discussed in reference to FIG. 1, includes a fingerprint imager 110 and fingerprint camera 120. Each will be discussed in turn.

The fingerprint imager 110 includes a light source 205, optics 210, and, optionally, active control circuits/element(s) 225. The light source 205 may be a coherent light source, such as a laser diode, which works efficiently with a HOE, or may be a non-coherent light source. The optics 210 includes optical elements 250, which are non-HOE's such as a slab waveguide, waveplate, polarizer, and lens(es), and at least one HOE, labeled 255 in FIG. 2, which includes a hologram.

The optional active control circuit/element(s) 225 may include an angle controller 230 and actuator 235. The actuator may be Direct Current (DC) motor, stepper motor, piezo-electric actuator, or other electro-mechanical device capable and adaptable for use in moving the light source 205 to positions and/or at angles fine enough for use in the fingerprint sensor 100. A wavelength controller 240 may also be employed in the imager 110, where the wavelength controller 240 may be used to change the wavelength of the light source 205, which, in turn, can compensate for temperature-induced changes in the angle for the Bragg matching condition of the HOE. A power controller 245 may also be employed by the imager 110 to control the output power and/or wavelength of the light source 205 for controlling exposure levels of the fingerprint 115.

The fingerprint camera 120 includes a sensor array 215 and electronics 220. The sensor array 215 may be a Charge Coupled Device (CCD) or Complimentary Metal Oxide Semiconductor (CMOS) and have a plurality of pixels arranged in a rectangular, or square pattern or other suitable pattern, providing a resolution fine enough for use in the fingerprint sensor 100. The electronics 220 are coupled to the sensor array 215 for receiving pixel data for processing. The electronics may include, by way of example, a processor, memory, A/D conversion, circuitry for variable shutter and/or integration time, and sensor data communications interface.

difference in actual signal level and a desired signal level corresponding to imaging performance.

For example, in the case of the fingerprint sensor 100, the feedback signal 395 may represent an angular error (i.e. mismatch from the Bragg matching condition of the HOE for light of a particular wavelength incident to the HOE) of the light beam emitting from the light source 205 and projecting onto the topological surface of the fingerprint, which may be caused by temperature effects on the optics 210. The camera logic 330 or microprocessor 335 may determine the feedback signal 395 based on the image data from the sensor array 215. The image data provided by the sensor array 215, for the purposes of feedback control, may include intensity data from a specific pixel in the sensor array, or data from a grouping of pixels in the sensor array or any combination thereof, or said image data used for feedback control may originate from at least one separate and independent sensor 386, providing signal 387 to camera electronics 220 for feedback control, that may comprise a plurality of sensors. The sensor array 215 may contain an additional light sensitive area 380, separate from the array of imaging pixels in the sensor array 215 and comprising one or more pixel, which may provide a signal 385 to the camera electronics 220 for the purposes of feedback control.

The camera electronics 220 may also provide a control signal 325 to the sensor array 215 for use during imaging of the fingerprint features or other topological features of the skin surface. The camera electronics may further include system memory 345 for storing image data following acquisition. The system memory 345 may also provide support for storing image data or partial image data during processing of the fingerprint image. The camera electronics 220 may further include microprocessor memory 355 for supporting the microprocessor 335. The microprocessor 335 and associated memory 355 may be used, for example, for processing the image data or calculating the feedback parameters in order to determine feedback signals 391, 392 or 395 or combinations thereof. Further, the camera electronics 220 may also include an interface circuit 360 for communicating with the local computer 130 via the communications link for transferring the image data 125 and fingerprint sensor control information 165 (see FIG. 1). The interface

curved surface may be a cone, and a subject whose palm print is taken places his or her palm wrapped around the outer surface of the cone. In another embodiment, the waveguide is a cone having an inner surface accessible and a subject placing his or her finger in contact with such inner surface. Accordingly, as used herein, the term "top waveguide surface" generally refers to the skin-proximal surface of the waveguide, i.e. the surface in contact with skin. As used herein, the term "bottom waveguide surface" refers to the sensor array-proximal surface of the waveguide, i.e. the surface opposite to the skin proximal surface.

Use of holographic optical elements (HOE) that comprise a photopolymer recording media attached to at least one support layer allows for a compact design without sacrificing resolution. However, certain important characteristics of the holographic optical element are very temperature sensitive. For transmission holograms, such as illustrated in FIG. 5, the fraction of light diffracted by the hologram depends both on the wavelength of the light, and its angle of incidence θ at the interface between HOE 410 and waveguide 405. Adequate diffraction efficiency occurs only in narrow wavelength and angular ranges that are determined by the angles of the recording conditions for the HOE, the thickness of the hologram medium, and the wavelength of the light used for recording the HOE (collectively determine so called Bragg selectivity or Bragg matching condition), and the wavelength of the light used to reconstruct the HOE. Without appropriate adjustments to the wavelength or incident angle, temperature changes of only a few degrees will significantly reduce or even eliminate holographic diffraction of a single hologram due to the effect of temperature on the refractive index of the hologram, the grating spacing and the grating angle.

Referring to FIG. 5, the intensity of diffracted light at temperature $T = T_1$ has a peak at an incident angle θ_1 to the HOE for a specific wavelength λ_1. As temperature changes from $T = T_1$ to $T = T_2$ to $T = T_3$, the peak of intensity of diffracted light at a fixed location along the z-axis shifts from an incident angle θ_1 to an incident angle of θ_2 to an incident angle θ_3, for a fixed incident wavelength λ_1. As a result, intensity of light diffracted to a fixed location z_0 along the z-axis decreases, thus significantly degrading the signal-to-noise (SNR) ratio. Similarly as

of beam 207 changes from α_1 to α_2 at entrance edge 604 when T changes from $T=T_1$ to $T=T_2$. It may be shown that the following relationship for holds true:

$$\alpha_2 - \alpha_1 = \frac{CTE_d L_1 - CTE_l L_3}{f} \Delta T, \qquad (1)$$

where $\Delta T = T_2 - T_1$, and CTE_d and CTE_l are the coefficients of thermal expansion for the light source (e.g., laser diode) mount and for the lens mount, respectively.

It is understood that a material that expands as temperature increases preferably also contracts as temperature decreases or vica versa. Thus, as used herein, the term "thermally expandable" means changing volume or length with temperature.

Alternate embodiments of this general concept include, but are not limited to, translating the lens element 602 in the y-direction, tilting waveguide 405 in the y-z plane, and/or moving and tilting a light source 205 provided that light source 205 outputs a collimated beam. In this latter embodiment, lens element 602 is integrated into the light source 205. These motions can all be achieved automatically via temperature induced changes in the dimensions of the structural elements that form the mechanical mounts for these optical components. These motions can be performed in any combination and those skilled in the art will be able to choose proper materials and dimensions for said mechanical mounts.

Referring back to FIG. 3 and to FIG. 6C and the inset, the fingerprint apparatus of this invention further comprises an electronically controlled actuator 390, such as a motor, that can be used to adjust the angle of incidence α by changing the vertical position of the lens element 602 with respect to the optical axis of light source 205, or by changing the vertical position of the light source 205 with respect to the optical center of lens element 602, such as shown in FIG 6C inset by vertical translation of the light source to a height position of $y = \Delta y$ at $T=T_2$. As depicted in FIG. 6C, the electronic actuator is represented by two separate motors 620 and 621 that drive the laser source 205 and the lens element 602, respectively in the y-direction to accommodate changes in incident angles at the entrance edge 604. There is a number of means by which the signal to drive the actuator can be obtained by one skilled in the art, and the methods depicted in FIG. 6C and its inset are intended to be illustrative but not limiting. In particular, it is desirable to use light diffracted

locations where its path of internal reflection is terminated by the presence of another surface, such as edge 690 of waveguide 405.

Alternatively, a second hologram, as well be detailed further in reference to the description of FIG. 7A, included specifically for the purpose of generating a servo feedback signal, can be recorded so as to be located in the vicinity of the main hologram of HOE 410. In one embodiment, this second hologram can be co-located with the main hologram by being co-locationally multiplexed.

Referring to FIG. 6D additional embodiments of the device of the present invention are shown. Specifically, entrance edge 604 is designed so that the incident ray 630 refracts as ray 630a towards bottom surface 612 of the waveguide 405. A portion of bottom surface 612 of waveguide 405 can be coated with a reflective layer (*e.g.* metal coating) labeled 614. Reflective layer 614 operates to protect waveguide 405 from smudges and other defects or contamination that may arise on bottom surface 612. These defects, if present, can add aberrations and regions of non-uniform beam intensity in the reflected beam 630e, such as by suppressing total internal reflection at locations of the defects, thereby possibly compromising the quality of the image collected by sensor array 215. It is preferable that reflective layer 614 only extend as far as would be required to protect the area of the first reflection of the incident light at surface 612. The extent of reflective layer 614 the z-direction should not block rays such as ray 630d from reaching sensor array 215.

In another embodiment waveguide 405 includes light traps 655 at edge 690, see FIG. 6D. Light traps 655 are designed to absorb substantially all of the light incident upon edge 690 and allow a minimum of light to reflect at edge 690. Suppressing such reflections (for example ray 630e that is undiffracted by HOE 410) minimizes the amount of spurious light that may illuminate the skin topology under examination and/or the amount of spurious light that is incident upon sensor array 215, which would otherwise reduce the SNR of the fingerprint system.

In another embodiment, shown in FIG. 6E, entrance edge 604 operates with optical power to optimize illumination of the location of the hologram of HOE 410. In FIG. 6E, entrance edge 604 as shown includes optical element 660. In this embodiment, lens element 602 (see FIGs. 6A-6D) can be eliminated. By way of example, optical power of entrance edge 604 can be designed to provide optimal

locations of dedicated areas of sensor array 215 are selected), by way of example, so as to be located at positions along the z-axis to independently detect the intensity of light diffracted by holograms 702 and 704, respectively. Sensors 720 and 722 can be located to detect the intensity of light diffracted by holograms 702 and 704 or instead to detect the intensity of the diffracted light from said holograms after the diffracted light has reflected at top surface 726 of skin contact layer 807. Preferably, although not a requirement, α_L, α_{HOE} and α_R are adjusted so that the intensities of light beam diffracted by hologram 702 and 704 and detected by the respective dedicated sensors are substantially equal at the values of incident angles for the Bragg matching condition of the respective holograms (shown as equal height peak in FIG. 7B). As can be seen from FIG. 7B, $\alpha_L < \alpha_{HOE} < \alpha_R$. As the result, as shown in FIG. 7C, when the angle for the Bragg matching condition of HOE 410 and holograms 702 and 704 changes due to temperature changing from T_1 to T_2, the dedicated sensors 720 and 722 will detect intensity of light beams diffracted from holograms 702 and 704 that are different from the respective intensities detected at temperature T_1 for the same angle of incidence α. The difference in intensity can be used to compute the control signals 393 or 396 or 398 or combinations thereof. It should be understood that logic 330 is designed to receive signals from the dedicated areas for processing differences in intensities.

An alternative embodiment comprises use of multiplexed holograms recorded in the photopolymer media of the HOE. The multiplexed holograms are recorded so that the Bragg selectivity's of these holograms are substantially overlapping. Use of multiplexed holograms that are recorded co-locationally can significantly reduce the sensitivity of the apparatus of this invention to temperature changes, or alignment changes, or wavelength changes, or combinations thereof. The multiplexed holograms, by way of example, can be multiplexed by the method of planar-angle multiplexing in a manner such that the increment of the recording angle is less than the width of the Bragg selectivity of each multiplexed hologram. Alternatively, these holograms can be multiplexed by varying the interbeam angle or the wavelength such that the grating period of each multiplexed hologram is slightly different so that the angular or wavelength selectivity characteristics of one such

camera microprocessor 335 in order to determine the correct operating wavelength to drive the wavelength controller 240.

In other embodiments, rather than changing the wavelength, a light source that has a broader wavelength spectrum can be used to reduce the sensitivity of the Bragg angle of the HOE to temperature change. Such light sources may include, for example, an LED or superluminescent LED. In these embodiments the incident angle α is held constant. As long as changes of the Bragg wavelength, produced by temperature changes of the HOE, are within the spectral bandwidth of the light source there will be a sufficient intensity of diffracted light to produce good imaging.

Other embodiments of the apparatus of this invention relate to physical construction of the device and will be described with reference to FIG. 6A. In one embodiment, entrance edge 604 of waveguide 405 forms an oblique angle to the top and bottom surfaces 610 and 612, said surfaces 610 and 612 being substantially parallel and planar surfaces. Use of an oblique angle for the entrance face of the waveguide advantageously reduces the thickness requirement for said slab waveguide. For example, with use of oblique angle for the entrance face, light beam 630 can be refracted directly towards top surface of waveguide 610 rather than towards bottom surface of waveguide 612 as it does in FIG. 6D. Refracting incident light 630 directly towards top surface, thereby eliminating the total internal reflection condition that is otherwise required for bottom surface of waveguide 612, reduces the z-dimension of waveguide 405. Alternatively, waveguide 405 can comprise inner and outer surfaces that may be curved so that a large topological surface of the skin can be placed on the outer surface at one time and imaged, such as could be the case when imaging the topological features of the surface of a palm. Again, use of an oblique angle for the entrance facet of the waveguide advantageously reduces the thickness requirement for said waveguide.

Other embodiments of the apparatus and method of this invention relate to the hologram recorded in the photopolymerizable media of the HOE. Referring to FIG. 8A, the apparatus of this invention preferably comprises HOE 410 that diffracts light (beam 826) in a direction that is not perpendicular to skin contact layer 807 so that the light reflected at the interface of skin contact layer 807 with air will not be

attached to skin contact layer 807, or it can be part of the cover plate, or it can be placed onto the cover plate before the fingerprint is captured. The pliable coating can be used to enhance image quality and reduce the dependence of SNR in the acquired fingerprint image on finger moisture or the wetting characteristic of the finger surface to skin contact layer 807 by improving the degree of optical contact between the surface topology of the skin of the finger and the skin contact layer.

In another embodiment skin contact layer 807 is formed from a material that has a refractive index that optimizes SNR of the captured image, such as fused silica, whereby the refractive index of the contact surface is similar to that of the surface of the finger or other skin surface.

Referring to FIG. 8D, the devices of the present invention can also include additional optical components. In one embodiment, the present invention includes wave plate 838, preferably ¼ waveplate, in combination with linear polarizer 840 to reduce detection of noise that can arise undesirably from sources such as diffuse and specular reflection. In this manner the contrast of the fingerprint image can be improved. In one configuration, ¼ wave plate 838 can be sandwiched between HOE 410 and skin contact layer 807 or 807A (see FIG. 8C), and the linear polarizer 840 is located between waveguide 405 and above sensor array 215. When linearly polarized light is diffracted from HOE 410 in a direction of ¼ wave plate 838, the polarization is transformed upon propagating through ¼ wave plate 838 to circularly polarized light. Upon reflection from either the top surface 726 of skin contact layer 807 or 807A or from ridge structure of the finger, the circularly polarized light is transformed by ¼ wave plate 838 back into linearly polarized light that has an electric field direction that is orthogonal to the original direction of the light entering HOE 410. When light, diffracted by HOE 410, interacts with the ridge structure of the finger surface that is in contact with the top surface 726 of skin contact layer 807 or 807A, both diffuse and specular reflections occur, with the former being stronger in some embodiments. When the diffracted light interacts with the top surface 726 of skin contact layer 807 or 807A at locations that correspond to a portion of skin surface that does not touch top surface 726 at these locations, only specular reflected light occurs. Detection of the noise contributions from the reflected light can substantially increase the level of grey-scale detected for portions of the captured

emitting diodes (LEDs) and/or semiconductor laser diodes. For reduced opto-mechanical alignment tolerances and simpler diffractive grating designs for HOE 410, it is desirable to collimate the radiation emitted from the light source. Lens element 602 is shown in FIG. 8A. Although a single transmissive lens is depicted, in general lens element 602 is composed of any combination of one or more transmissive and/or reflective optical elements such that the net optical effect is a substantial collimation of radiation emitted by light source 205. The collimated light emerging from lens element 602 is incident upon entrance edge 604 of waveguide 405. The angle φ_{SB} of the entrance edge 604 is specified so that optical axis 804 of the incident light beam propagating at an angle θ_1 (relative to the z-axis) is refracted at entrance edge 604 so that beam 822 propagates at an angle θ_{SB} with respect to the normal to the interface between waveguide 405 and HOE 410. As a result, a sufficiently large footprint of light illuminates HOE 410 and therefore illuminates finger 105 or other topological surface of the skin.

Referring to FIG. 8A, thickness T is defined as the distance that separates the top 726 of skin contact layer 807 to surface 814 of sensor array 215. For compactness of the device and in order to reduce the thickness T, which plays a role in defining the spatial resolution of the fingerprint sensor, it is desirable that the angle θ_{SB} be large, for example greater than about 70° but it is preferable that θ_{SB} be less than about 80° for otherwise the device will exhibit large sensitivity to thermal changes. By way of example, for $\theta_{SB} = 79°$ and a substrate block of thickness $T_{SB} = 3.3$ mm approximately 17 mm [3.3·tan(79°)] length of the skin topology can be imaged in the z-direction. For the case of $\theta_{SB} = 79°$, then with $\theta_1 = 17.5°$, and the substrate block composed of a material of index 1.53, $\varphi_{SB} = 90.9°$. Note that by having light source platform 662 tilted below the horizon, the opto-electro-mechanical components of the fingerprint sensor are allowed to lie below skin contact layer 807, thereby allowing for the housing 818 to be flush with said cover slide top.

Continuing to refer to FIG. 8A, the light, incident upon waveguide 405/HOE 410 interface, is refracted into HOE 410. In one embodiment, holographic grating of HOE 410 is a volume grating. One skilled in the art can design and engineer a

In one embodiment, there are several films, 810, 811 and 812, disposed between waveguide 405 and detector cover 813. These films may be arranged in many different manners, but their purpose serves to suppress reflections of light, in addition to filtering out unwanted noise. In one embodiment, film 810 is a linear polarizer film. Polarizer 810 preferentially has a polarization orientation substantially parallel to the polarization of the incident light ray 822. As such, polarizing film 810 suppresses portions of diffracted beam 826 that are scattered by finger 105 (and hence depolarized) from reaching sensor array 215. Film 811 is a wavelength filter. Wavelength filter 811 is preferentially tuned so that it substantially transmits wavelengths of light emitted by light source 205, and blocks all other wavelengths, and as such rejects ambient light originating outside of the housing 818 that would otherwise be incident upon sensor array 215. Film 811, by way of example, can be a dichroic film coating or a material that absorbs the desired spectral distribution of the ambient light, such as can be the case for a dyed plastic. Note that the wavelength filtering properties of film 811 can be incorporated into the bulk material or as a coating on either waveguide 405, skin contact layer 807, and/or detector cover 813, thereby eliminating the need for wavelength filter 811. Film 812 is an index-matching material where the index of refraction of said material preferentially matches within about 0.15 to the index of refraction of film 811 and detector cover 813. As a result, the intensity of reflected light at the interfaces of film 812 is not greater than about 0.25% of the intensity of the incident light at the boundaries of film 812. Alternatively, if index-matching material is not desired, it is preferred that the space shown occupied by film 812 be replaced by a small air gap (for example, approximately 0.1 to 0.2 mm) and that the film 811 and detector cover 813 each have an anti-reflection (AR) coating on their two opposing surfaces.

The light transmitted by detector cover 813 is incident upon sensor array 215. In one embodiment, sensor array 215 comprises a plurality of detector elements that enable a 2-D image of the fingerprint to be captured. Sensor array 215 can be a 2-D or 1-D charge coupled device (CCD), but is preferentially a detector requiring lower electrical power such as a 2-D or 1-D CMOS device. For the reduction of stray light, which for a coherent light source can lead to the creation of interference fringes that may be mistakenly construed for features on the skin being

skin contact layer 807 and the skin, but is minimized for the interface between skin contact layer 807 and air.

FIG. 8B depicts a top-down view of the embodiment of the device shown in FIG. 8A. In one embodiment, the width of the beam in the *x*-direction illuminating waveguide 405 and hence the illuminated width of finger 105 is dictated by the width of the beam that enters lens element 602. For the embodiment of light source 205 containing at least one semiconductor laser, the divergence of a semiconductor laser diode is anamorphic. With such an anamorphic beam, the angle of rays 823 (see FIG. 8A) and 824, emerging from light source 205 and representing the 50% drop in intensity level of the beam, will make angles of θ_s and θ_f, respectively, with respect to optical axis 804. For typical laser diodes, the ratio of these two angles is approximately 3:1, which means the beam is substantially elliptical in a cross section perpendicular to optical axis 804.

By way of example, consider the specification that the fingerprint device must be capable of examining a 17 x 17 mm area of skin. As illustrated earlier, a thickness T_{SB} of 3.3 mm can accommodate the 17 mm skin size in the *z*-direction. To accommodate the 17 mm in the *x*-direction, the waveguide must be at least 17 mm wide in this direction (as does the beam width of light in the *x*-direction from light source 205 that illuminates entrance edge 604). Therefore entrance edge 604 is substantially rectangular having dimensions in *x* and *y* of 17 mm and 3.3 mm, respectively. For maximum light efficiency, it is preferable that the fast axis of the laser (e.g., the axis of the laser that diverges the fastest), with full width at half maximum (FWHM) of $2\theta_f$, be in the direction of the 17mm width of waveguide 405 (corresponding to the *x*-axis). Likewise, the slow-axis (axis of the laser that diverges the slowest) having FWHM of $2\theta_s$, will correspond to the direction of the 3 mm thickness of waveguide 405.

In addition to the mechanical matching of beam widths and footprints for the area to be imaged of the topological surface of the skin, use of a diffraction optical element 410, that operates to diffract light so as to illuminate said surface of the skin, is generally polarization dependent. Consequently, use of correct polarization is preferred to achieve good SNR of the system. For a single transverse mode laser

Patent Application US 2003/0007201, the teachings of which are herein incorporated by reference in their entirety. Briefly, the diffraction efficiency of a hologram is a periodic function of the value of the grating strength of the hologram, which is dependent upon a material property, namely the value of its refractive index modulation. For photopolymer recording materials, the refractive index modulation, in turn, depends primarily on the degree of chemical segregation achieved in the recording material of the polymerizable component and the binder and the relative refractive index difference between the polymerizable component and the binder in the recording material, but it also may depend on thickness of the recording material, angles of incidence of the beams used to record the hologram and thereby the grating period, as well as the wavelength of the light used to record the hologram. For a given refractive index modulation achieved by the recording material, the grating strength is dependent upon similar parameters such as grating period, thickness, and wavelength. A hologram is optimized for a particular polarization when it is recorded using such combination of the above parameters that the resulting value of refractive index modulation corresponds to a peak of the diffraction efficiency. Ordinarily, the peaks of diffraction efficiencies of the holograms optimized for s- and p-polarized light do not occur at the same values of the refraction index modulation or grating strength (i.e. same values of the above-mentioned parameters). However, using the periodicity of the diffraction efficiency as a function of the value of the refractive index modulation or grating strength, it is possible to record a hologram that is optimized for both s- and p-polarized light. Since any light wave can be described as superposition of s- and p-polarized waves, a hologram that is simultaneously optimized for s- and p-polarized light is said to be polarization independent.

In the preferred embodiment of the device of the present invention, beam blocks 816 and 817 are integrated into the design. Beam block 816 is designed such that light from light source 205 does not enter sensor array 215 or any of the film layers, 810 through 812. Beam block 817 is designed so that light from light source 205 does not impinge onto finger 105, HOE 410, or skin contact layer 807. Both beam blocks 816 and 817 are positioned as close to entrance edge 604 as possible in order to minimize adverse diffraction effects due to the clipping of the light beam,

The grating geometry of FIG. 9 has the advantage that beam expansion in the *xz* plane is accomplished. The achieved beam expansion of the incident beam of diameter D_i is given by

$$\frac{D_r}{D_i} = \frac{\cos\theta_{-1}}{\cos\theta_i}, \tag{5}$$

where θ_{-1} is the angle of the diffracted -1st order reflected beam 901 measured relative to the grating surface normal 902 and θ_i is the angle of incidence of the incident beam 903 relative to grating surface normal 902.

As an example of such a reflective anamorphic beam expanding grating, consider a 1600 lp/mm reflection grating. Consider further that light source 205 is a semiconductor diode laser of 655 nm wavelength radiation and that beam 903 is incident upon said 1600 lp/mm reflection grating at $\theta_i = 85°$. The resultant diffracted negative first order propagates at $\theta_{-1} = 2.97$ and the expansion ratio D_r/D_i achieved is 11.5. Note that one skilled in the art can design and engineer other gratings (for example, surface-relief or volume), including gratings wherein the incident beam 903 transmits through a substrate such that it illuminates the grating from inside of the substrate material (for example a glass) which then transmits the required diffraction order for achieving the level of anamorphic beam expansion required. Whether a transmission or a reflection grating is designed to perform the required anamorphic beam expansion in the *xz* plane, it is preferable that the grating have a sufficiently high frequency such that a minimum number of diffraction orders propagate other than the order of interest. In this manner, one can make the distance between the grating 904 and the waveguide 405 as short as possible such that only a single diffraction order enters into the substrate block.

In the embodiment shown in FIG. 9, the diffracted beam 901 travels substantially parallel to the z-axis. The geometry of the fingerprint sensor illustrated in FIGs. 8A and 8B indicates the preference for a HOE 410 that has grating fringes that are primarily tilted in the *y-z* plane, but are approximately uniform along the *x*-direction. As such, HOE 410 has Bragg-matching conditions that require fractions of a degree of control of the light propagation angle in the *y-z* plane, but less stringent (>5 degrees) requirements for the angle of light propagation in the *x-z*

In 2003, 6.5 years later, said Polaroid photographic image was digitized by scanning at 600 dpi, and used as a training template for an example of the fingerprint correlation software of this invention. A new image of the same finger was acquired in 2003 using a fingerprint imager of this invention comprising the optical design of FIG. 4. The captured fingerprint was compared to the scanned image of the 6.5-year-old photograph of the original fingerprint. A positive identification, using locations of pores, the fine detail of the ridge contour at the boundaries of ridges and valleys, and minutiae was readily achieved, even though the said original and new images represent a finger area only 1/8" by 1/8", scale and rotation were different, the photograph had distortions due to being obtained from an image of the original fingerprint as displayed on a curved surface of a video monitor, and contrast and exposure were not matched nor calibrated in any way. At least 50 features, including 45 pores and 5 minutia points were captured from the original scan of the 1996 image, of which 22 pores and 5 minutia were present, detected and matched in the captured fingerprint imaged in 2003. The successful correlation results show that including pores in the fingerprint as well as the fine details of the ridge contour, by use of an apparatus that is capable of acquiring fingerprint images at high resolution, greatly increases the number of features that can be used for image correlation and significantly enhances the reliability of fingerprint comparison. Beneficial effects of the enhancements provided by the apparatus and method of this invention provide for reducing the occurrence of false acceptance, improving (through use of multiple templates) false reject rates, and significantly reducing the fingerprint sample area required for positive unique and deterministic authentication and identification.

FIG. 10 shows the Bragg detuning characteristics for 8 co-locationally multiplexed slant fringe plane-wave holograms recorded in 50 micron thick USLH-500-7A Aprilis holographic recording medium. Recording was carried out in the conventional manner using angle multiplexing where the increment of the recording angles for each of the co-locationally multiplexed holograms corresponds to twice the value for the full angle width at half height of the respective Bragg detuning curves. Each hologram was recorded with equal beam intensities of 4 mW in the Reference and Signal beam paths using spatially filtered and collimated light with a fixed value for the interbeam angle of 48.6°, and the sample was rotated about the

CLAIMS

1. An apparatus for fingerprint image acquisition comprising:

a waveguide, having an entrance edge and top and bottom surfaces;

a light source, configured to direct a light beam toward the entrance edge of the waveguide;

a skin contact layer, disposed at or near the top surface of the waveguide or bottom surface of the waveguide;

a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer;

a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer,

wherein the HOE includes

a layer comprising a grating; and

at least one supporting layer in contact with the said grating layer, wherein the grating layer and the at least one supporting layer have substantially similar coefficients of thermal expansion or thermo-optic coefficients or both.

2. An apparatus for image acquisition of topological features of the surface of skin comprising:

a waveguide, having an entrance edge and top and bottom surfaces;

a light source, configured to direct a light beam at the entrance edge of the waveguide;

a skin contact layer, disposed at or near the top surface or the bottom surface of the waveguide;

a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer;

a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer; and

wherein the means for compensating includes means for mounting one or more of the light source, the lens element or the waveguide, and

wherein the means for mounting is thermally expandable and is configured to adjust the angle of incidence of the light beam onto the waveguide or the HOE.

10. The apparatus of Claim 9 wherein the means for mounting one or more of the light source, the lens element or the waveguide comprises a rod or bar.

11. The apparatus of Claim 2 wherein the means for compensating includes one or more actuators, configured to adjust the angle of incidence of the light beam onto the waveguide or the HOE.

12. The apparatus of Claim 11 wherein further including an optional lens element.

13. The apparatus of Claim 12 wherein the actuator adjusts the position of one or more of the light source, the lens element or the waveguide.

14. The apparatus of Claim 12 wherein the position of one or more of the light source, the lens element or the waveguide is manually controlled by measuring intensity of the light diffracted by the HOE and detected by one or more of a plurality of pixels of the sensor array.

15. The apparatus of Claim 13 wherein the actuator is electronically controlled.

16. The apparatus of Claim 15 wherein intensity of the light reaching one or more of a plurality of pixels of the sensor array is measured to provide a signal that is used to control the actuator.

wherein the HOE includes at least two co-locationally multiplexed holograms.

22. The apparatus of Claim 21 wherein the multiplexed holograms are configured so that the Bragg matching condition of the multiplexed holograms is substantially overlapping.

23. The apparatus of Claim 21 wherein the multiplexed holograms are planar-angle multiplexed and wherein the increment of the recording angle for multiplexing is less than the width of the angle Bragg matching condition of each earlier-recorded multiplexed hologram.

24. The apparatus of Claim 21 wherein the grating periods of the multiplexed hologram are not equal.

25. An apparatus for image acquisition of topological features of the surface of skin comprising:

a waveguide, having an entrance edge and top and bottom surfaces;

a light source, configured to direct a light beam at the entrance edge of the waveguide;

a skin contact layer, disposed at the top or bottom surface of the waveguide;

a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source at the skin contact layer;

a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer; and

means for changing the wavelength of the light source.

26. The apparatus of Claim 34 wherein the means for changing the wavelength of the light source is a laser diode configured to change the operating

wherein the light source is a broad wavelength spectrum light source, the wavelengths of which can reconstruct the HOE.

33. The apparatus of Claim 32 further including a lens element, configured to direct the light beam from the light source at the entrance edge of the waveguide.

34. The apparatus of Claim 32 wherein the HOE is configured to diffract the light beam in a direction that differs from the perpendicular to the skin contact layer by an angle

35. The apparatus of Claim 34 wherein the HOE has a diffraction efficiency of at least about 50%.

36. The apparatus of Claim 34 wherein the HOE has a diffraction efficiency of at least about 75%.

37. The apparatus of Claim 34 wherein the HOE has a diffraction efficiency of at least about 90%.

38. The apparatus of Claim 32 wherein the HOE includes at least two multiplexed holograms.

39. The apparatus of Claim 32 wherein the HOE is optimized for s-polarized incident beam.

40. The apparatus of Claim 32 wherein the HOE is optimized for p-polarized incident beam.

41. The apparatus of Claim 32 wherein the HOE is polarization independent.

52. The apparatus of Claim 32 wherein the skin contact layer has a refractive index that is between about 1.30 and about 1.50.

53. The apparatus of Claim 32 wherein the skin contact layer comprises a portion having optical power configured to direct the light reflected from the interface between skin and the skin contact layer to the sensor array.

54. The apparatus of Claim 53 wherein the portion having optical power is curved.

55. The apparatus of Claim 53 wherein the portion having optical power is a plano-convex lens.

56. The apparatus of Claim 32 further including an additional lens element attached to the skin contact layer configured to direct the light reflected from the interface between skin and the skin contact layer to the sensor array.

57. The apparatus of Claim 32 wherein the skin contact layer comprises layer of a polymer having a glass transition temperature less than ambient use temperature of the device.

58. The apparatus of Claim 32 wherein the skin contact layer is coated with a layer of polymer having a glass transition temperature less than ambient use temperature of the device.

59. The apparatus of Claim 32 wherein the skin contact layer comprises a glass material having refractive index between about 1.45 and 1.50.

60. The apparatus of Claim 32 wherein the skin contact layer comprises a top surface having surface energy of less than about 30 mJ/m^2.

70. The apparatus of Claim 69 wherein the dielectric layer includes derivatives of silicone or siloxane.

71. The apparatus of Claim 32 wherein the sensor array has a resolution of at least 1100 pixels per inch in the acquired image.

72. The apparatus of Claim 32 wherein the sensor array is a CCD or CMOS imagers.

73. A method of acquiring an image of the topology of the surface of skin, comprising:

receiving a surface of skin by a device for image acquisition of the topological features of the surface of skin wherein said device includes a holographic optical element (HOE) having a Bragg matching condition;

directing a light beam at the HOE, thereby diffracting the light beam;

directing the diffracted light beam at the interface between skin and the skin contact layer, thereby reflecting the light beam;

compensating for temperature-induced changes in the Bragg matching condition of the HOE; and

detecting the reflected light, thereby acquiring the image of the topological features of the surface of skin by said device.

74. The method of Claim 73 wherein compensating for temperature-induced changes in the Bragg matching condition of the HOE includes controlling the temperature of the HOE.

75. The method of Claim 73 wherein the HOE includes a diffraction grating having at least one dimension that is greater than the cross-section of the light beam, and

wherein the light beam is directed at the HOE at an angle that is less than about 90° with respect to the plane of the HOE, said HOE diffracting

mounting means to be thermally expandable and configuring the selected means to adjusts the angle of incidence of the light beam onto the HOE.

80. The method of Claim 79 wherein the means for mounting the light source is a thermally expandable rod or bar.

81. The method of Claim 79 wherein the image acquisition device further includes a controllable actuator, configured to adjust an angle of incidence of the light beam onto the HOE.

82. The method of Claim 76 wherein the position of one or more of the light source, the lens element or the waveguide is manually controlled by measuring the intensity of the light diffracted by the HOE and detected by one or more of a plurality of pixels of the sensor array.

83. The method of Claim 76 wherein the device further includes at least one additional sensor, and

further wherein the position of one or more of the light source, the lens element or the waveguide is manually controlled by measuring the intensity of the light diffracted by the HOE and detected by the at least one additional sensor.

84. The method of Claim 81 wherein compensating for the temperature-induced changes in the Bragg matching condition of the HOE includes controlling the actuator by an electrical signal.

85. The method of Claim 84 wherein the device further includes at least one additional sensor, and

wherein controlling the actuator includes measuring intensity of the light reaching the sensor array or at least additional sensor, thereby providing the electrical signal.

92. The method of Claim 78 wherein the light source is a laser diode, and wherein compensating for temperature-induced changes in the Bragg matching condition of the HOE includes configuring the laser diode to change the operating wavelength in response to temperature.

93. The method of Claim 76 wherein compensating for temperature-induced changes in the Bragg matching condition of the HOE includes configuring the light source to produce a broad wavelength spectrum light.

94. The method of Claim 76 further including selecting the HOE that diffracts the light beam in a direction that differs from the perpendicular to the skin contact layer by an angle that exceeds the angular width of the Bragg angle selectivity of the main hologram.

95. The method of Claim 76 further including selecting the HOE that includes at least two multiplexed holograms.

96. The method of Claim 94 further including selecting the HOE so that each of the multiplexed holograms has a diffraction efficiency of at least about 50%.

97. The method of Claim 94 further including selecting the HOE so that each of the multiplexed holograms has a diffraction efficiency of at least about 75%.

98. The method of Claim 94 further including selecting the HOE so that each of the multiplexed holograms has a diffraction efficiency of at least about 90%.

99. The method of Claim 73 further including selecting the HOE that is optimized for s-polarized light.

100. The method of Claim 73 further including selecting the HOE that is optimized for p-polarized light.

light reflected from the interface between skin and the contact layer at the sensor array.

110. The method of Claim 76 wherein the skin contact layer comprises layer of a polymer having a glass transition temperature less than ambient use temperature of the device.

111. The method of Claim 76 wherein the skin contact layer is coated with a layer of polymer having a glass transition temperature less than ambient use temperature of the device.

112. The method of Claim 76 wherein the skin contact layer comprises a glass material having refractive index between about 1.45 and 1.50.

113. The method of Claim 76 wherein the skin contact layer comprises a top surface having surface energy of less than about 30 mJ/m^2.

114. The method of Claim 76 further including at least one of a ¼ wave plate and a linear polarizer disposed between the skin contact layer and the sensor array.

115. The method of Claim 114 wherein the ¼ wave plate is disposed between the HOE and the skin contact layer and the linear polarizer is disposed between the waveguide and the sensor array.

116. The method of Claim 76 wherein the light source wavelength that is in a range from about 400 nm to about 1000 nm.

117. The method of Claim 116 wherein the light source wavelength is in a range from about 400 nm to about 535 nm.

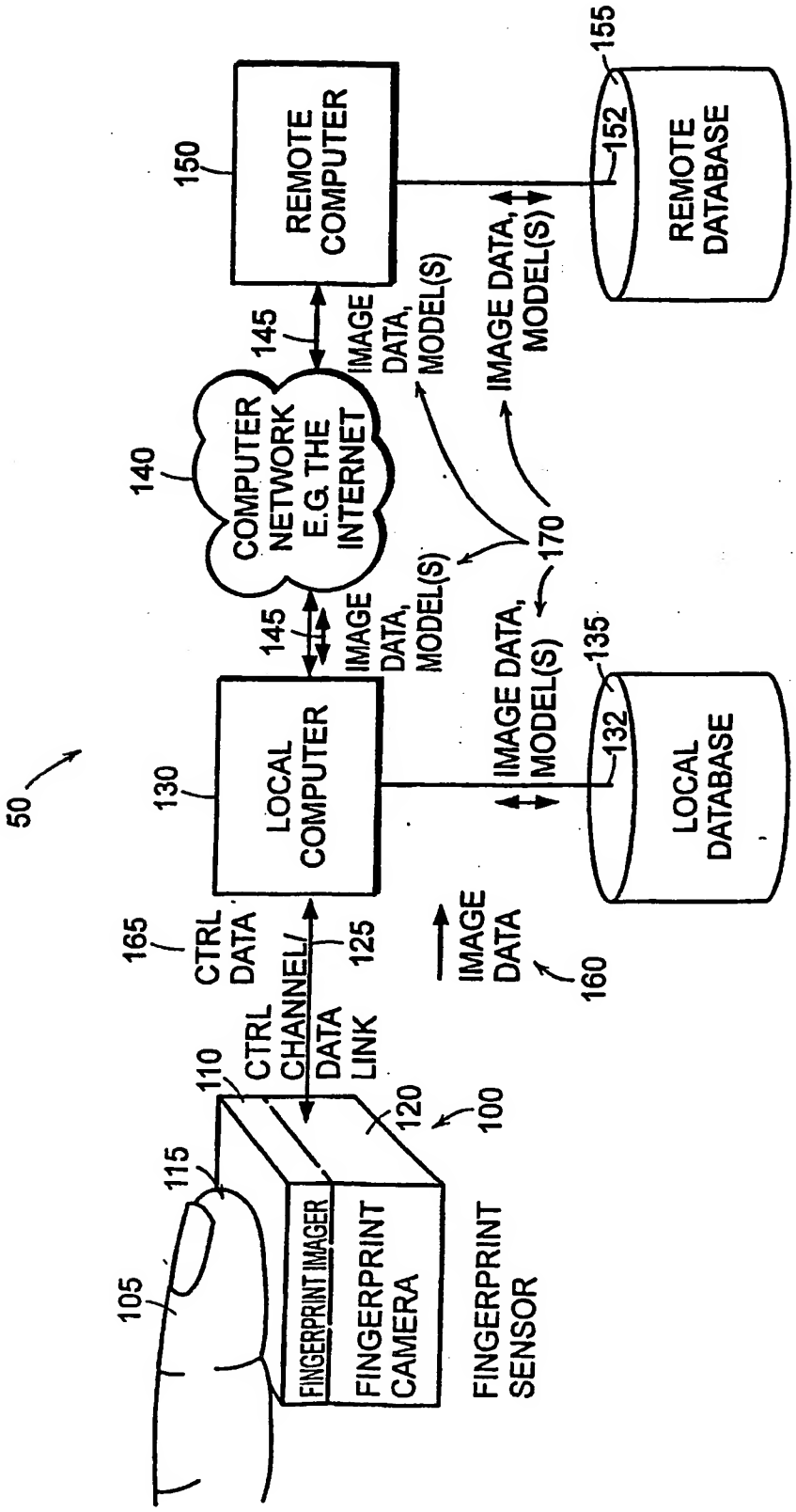

50
REMOTE COMPUTER
150
REMOTE DATABASE
152
155
IMAGE DATA, MODEL(S)
COMPUTER NETWORK E.G. THE INTERNET
140
145
IMAGE DATA, MODEL(S)
170
LOCAL COMPUTER
130
LOCAL DATABASE
132
135
IMAGE DATA, MODEL(S)
CTRL DATA
165
CTRL CHANNEL/ DATA LINK
125
IMAGE DATA
160
110
120
100
115
FINGERPRINT IMAGER
FINGERPRINT CAMERA
FINGERPRINT SENSOR
105

FIG. 1

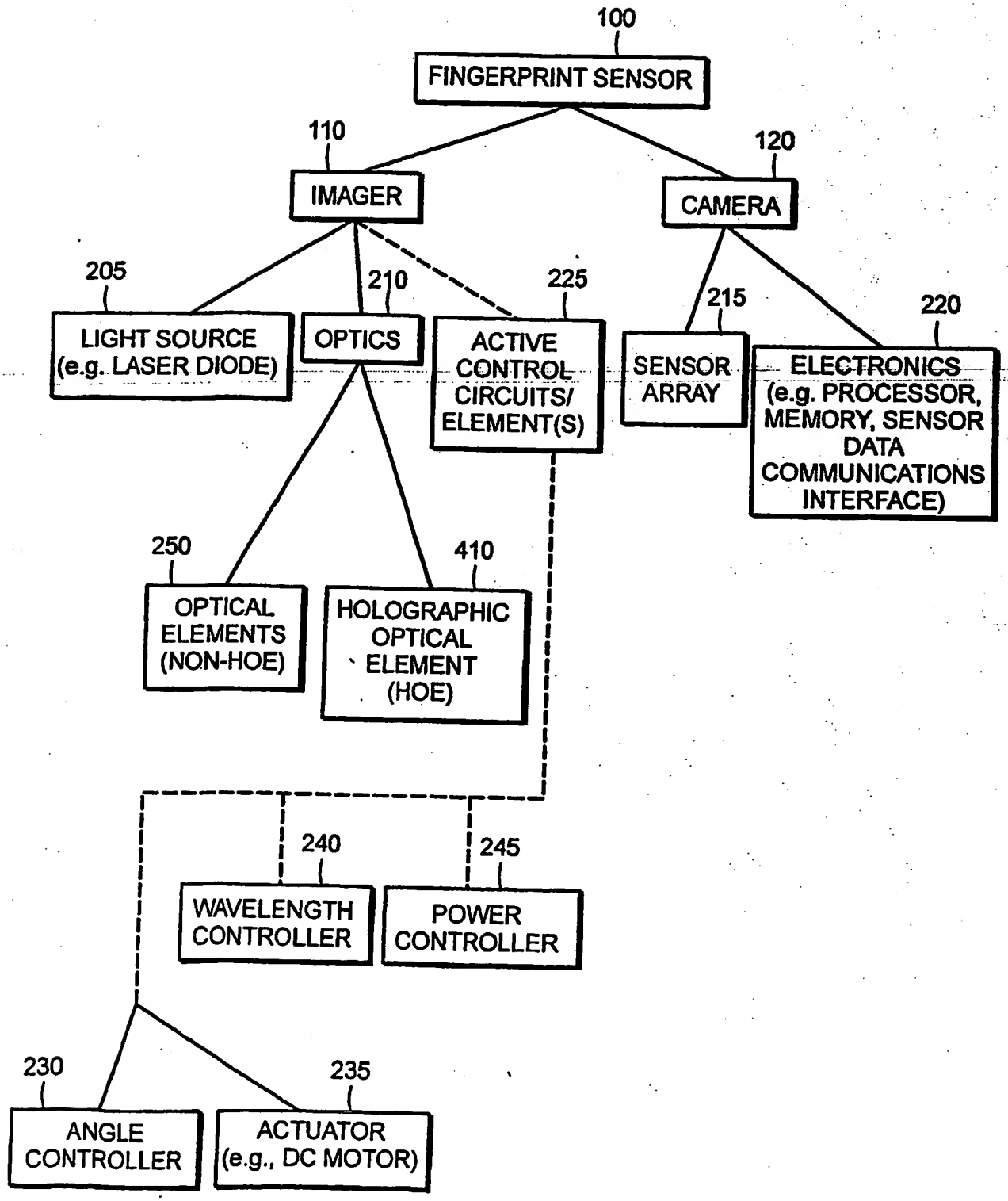

100
FINGERPRINT SENSOR
110
IMAGER
120
CAMERA
205
LIGHT SOURCE (e.g. LASER DIODE)
210
OPTICS
225
ACTIVE CONTROL CIRCUITS/ ELEMENT(S)
215
SENSOR ARRAY
220
ELECTRONICS (e.g. PROCESSOR, MEMORY, SENSOR DATA COMMUNICATIONS INTERFACE)
250
OPTICAL ELEMENTS (NON-HOE)
410
HOLOGRAPHIC OPTICAL ELEMENT (HOE)
240
WAVELENGTH CONTROLLER
245
POWER CONTROLLER
230
ANGLE CONTROLLER
235
ACTUATOR (e.g., DC MOTOR)

FIG. 2

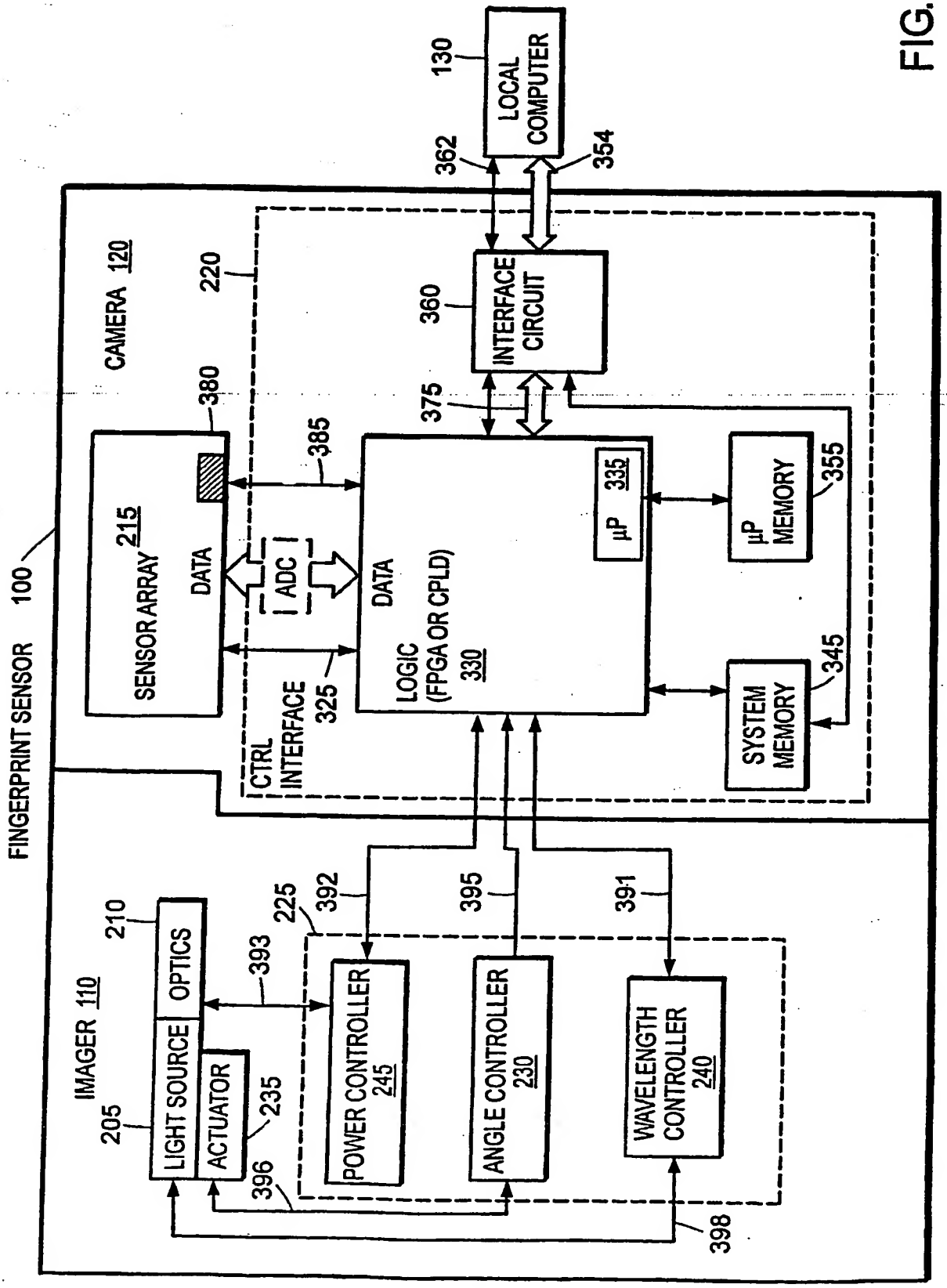

FINGERPRINT SENSOR 100
CAMERA 120
220
130
LOCAL COMPUTER
362
354
360
INTERFACE CIRCUIT
375
380
385
SENSOR ARRAY 215
DATA
ADC
DATA
LOGIC (FPGA OR CPLD) 330
µP 335
µP MEMORY 355
SYSTEM MEMORY 345
CTRL INTERFACE 325
IMAGER 110
210
OPTICS
LIGHT SOURCE 205
ACTUATOR 235
393
225
392
395
391
POWER CONTROLLER 245
ANGLE CONTROLLER 230
WAVELENGTH CONTROLLER 240
396
398

FIG. 3

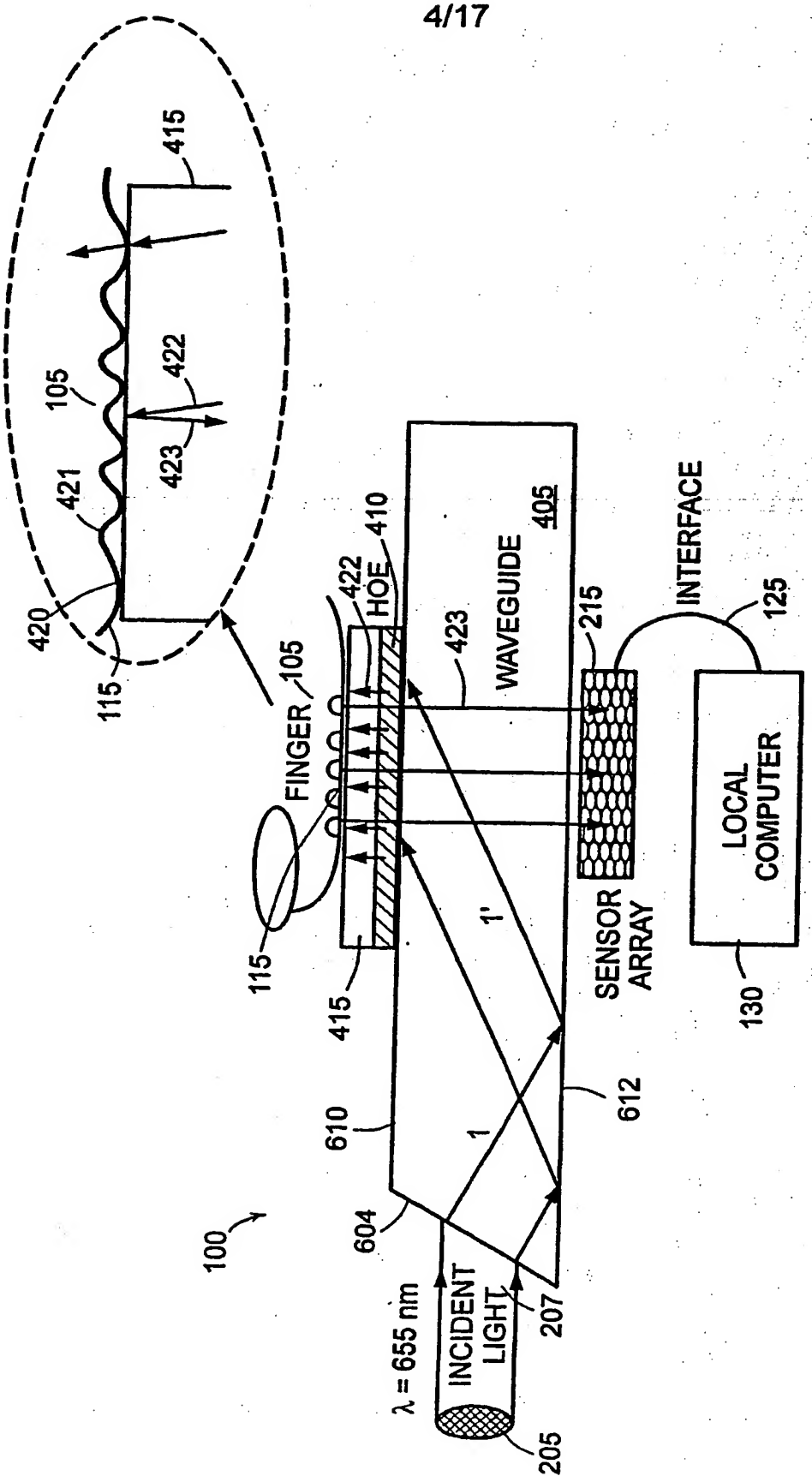

415
105
422
423
421
420
115
410
HOE
422
405
WAVEGUIDE
423
215
INTERFACE
125
FINGER
105
115
415
1'
SENSOR ARRAY
LOCAL COMPUTER
130
610
1
612
604
100
λ = 655 nm
INCIDENT LIGHT
207
205

FIG. 4

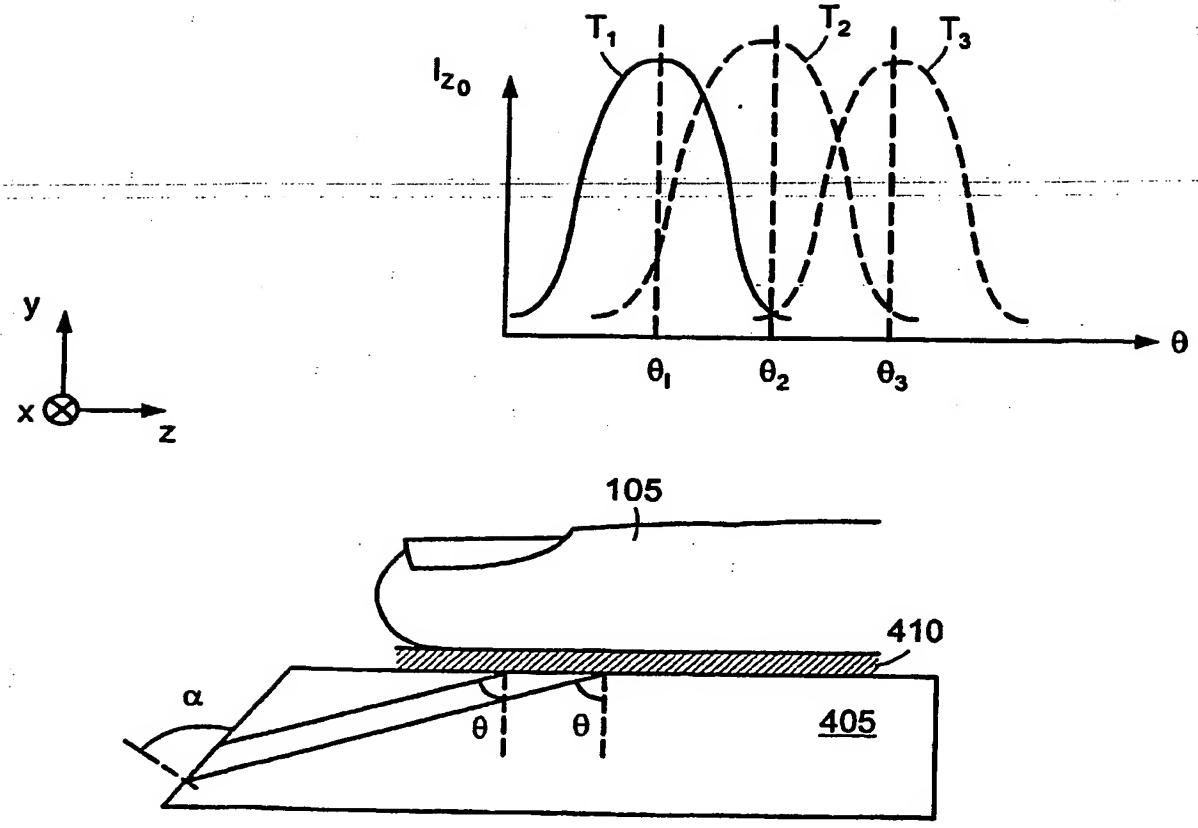


FIG. 5

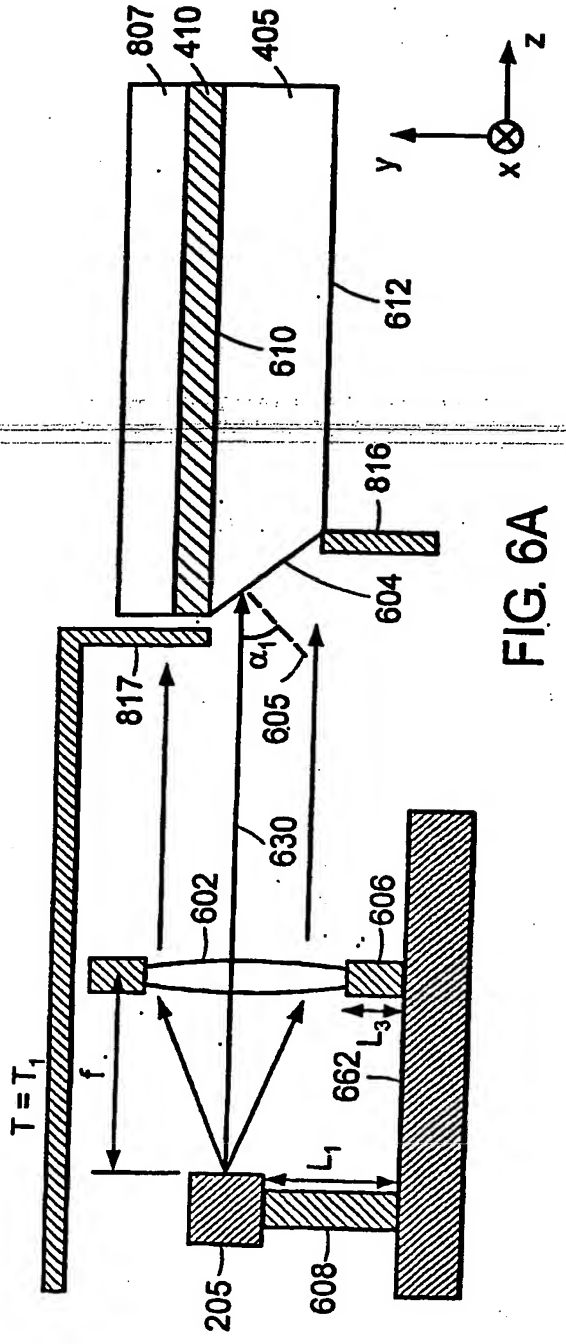

807
410
405
z
y
x
612
610
816
604
α_1
605
817
630
602
606
$T = T_1$
f
L_3
662
L_1
205
608

FIG. 6A

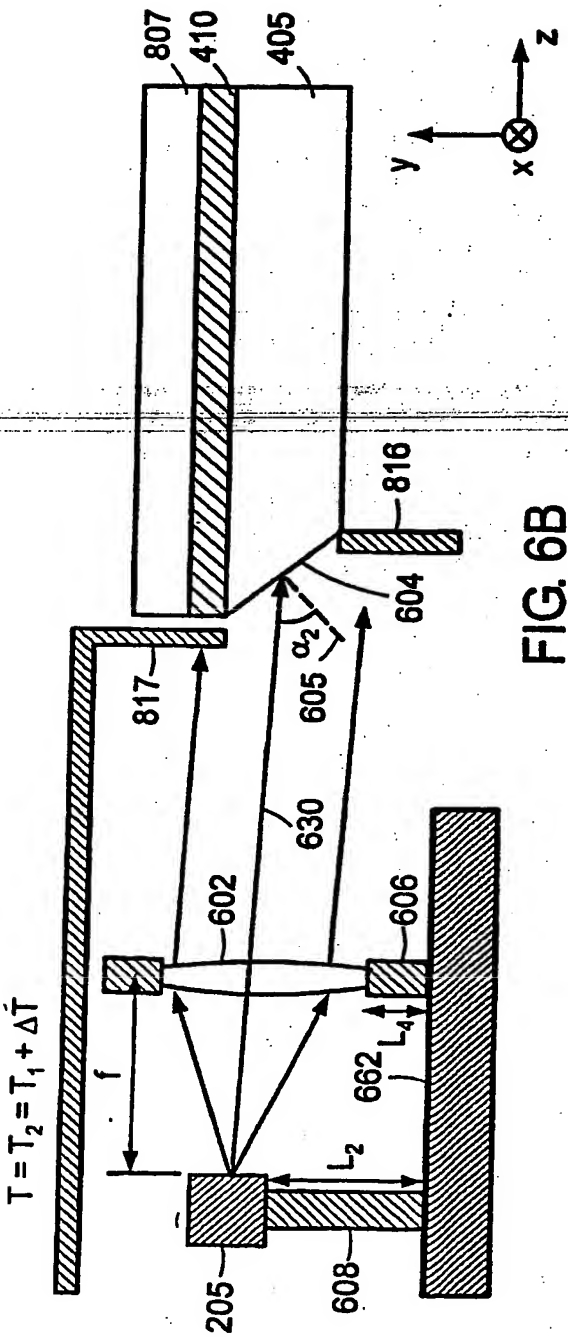

807
410
405
z
y
x
816
604
α_2
605
817
630
602
606
$T = T_2 = T_1 + \Delta T$
f
L_4
662
L_2
205
608

FIG. 6B

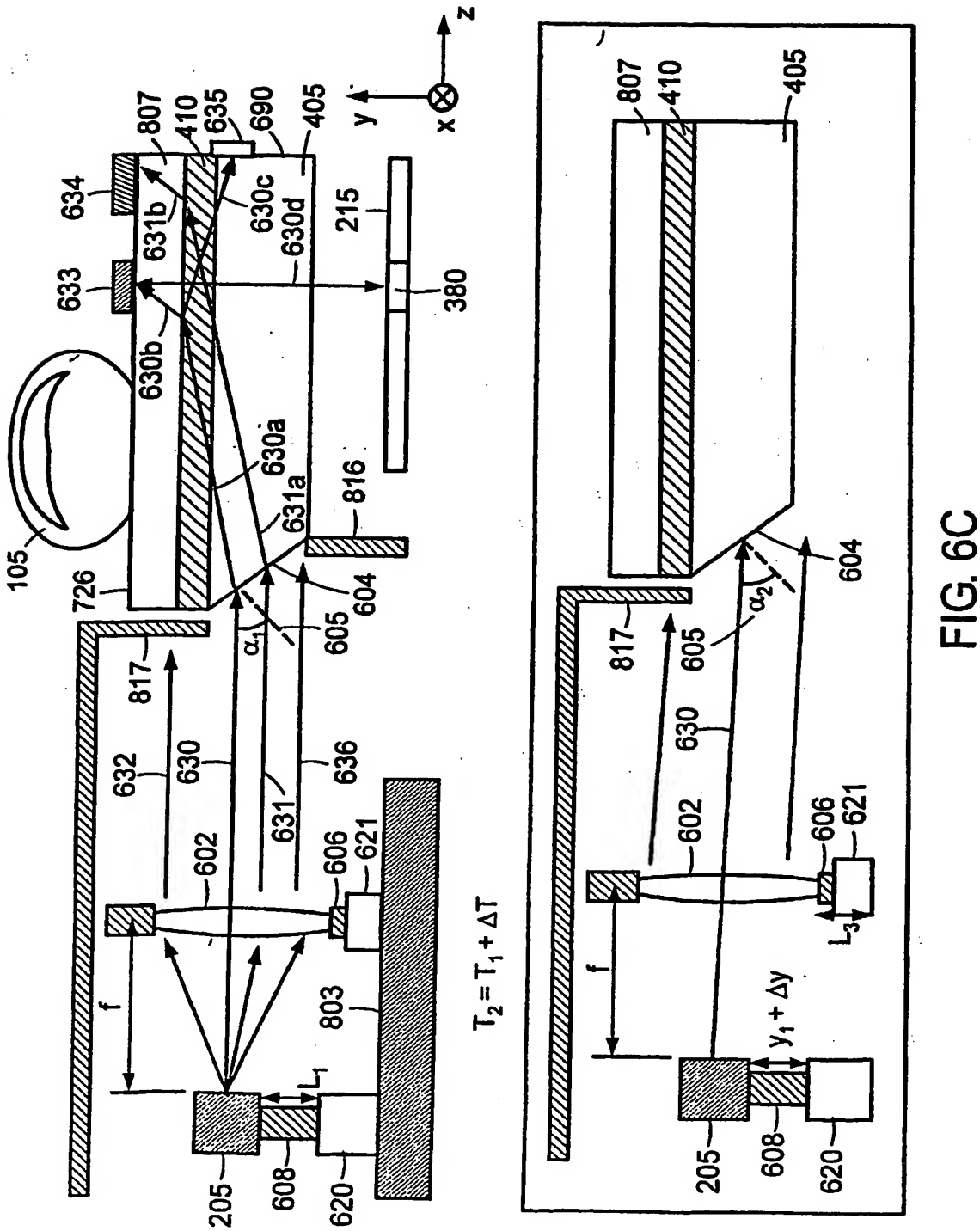

z
y
x
807
410
635
690
405
634
631b
630c
630d
215
633
380
630b
630a
631a
816
105
726
604
605
α_1
817
632
630
636
631
602
606
621
f
803
L_1
205
608
620
$T_2 = T_1 + \Delta T$
807
410
405
604
α_2
817
605
630
602
606
621
L_3
f
$y_1 + \Delta y$
205
608
620

FIG. 6C

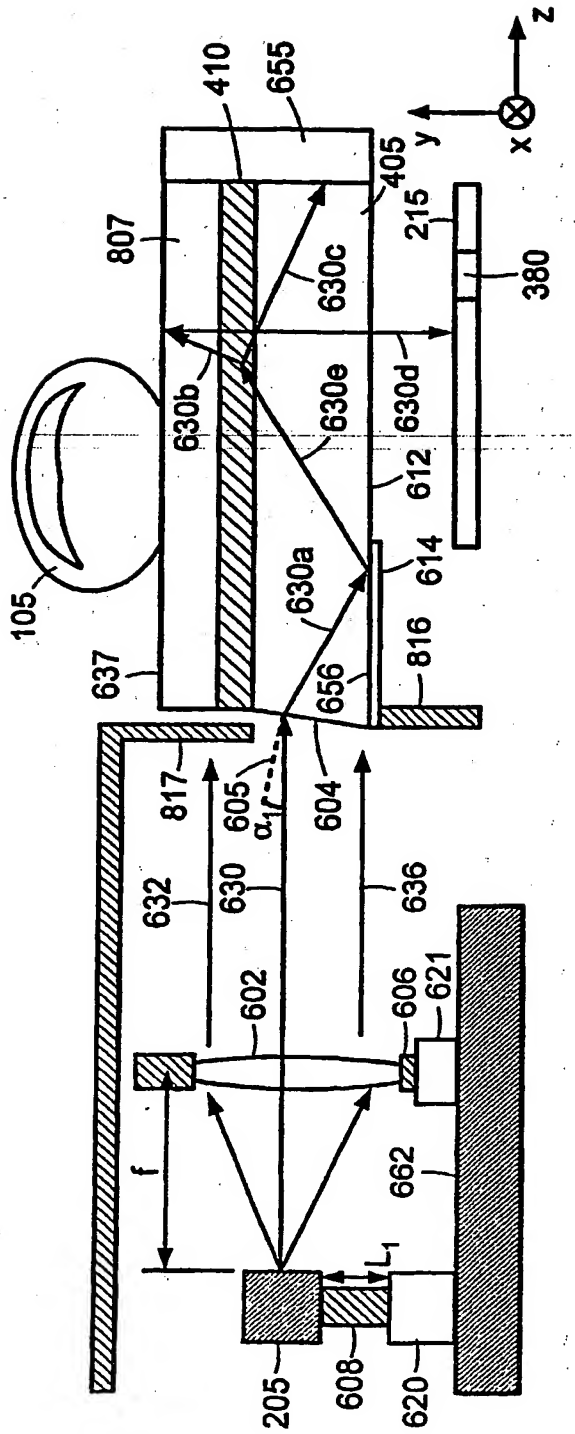

z
y
x
410
655
405
215
380
807
630c
630b
630e
630d
612
614
630a
105
816
637
656
604
605
α_1
817
632
630
636
602
606
621
662
f
L_1
205
608
620

FIG. 6D

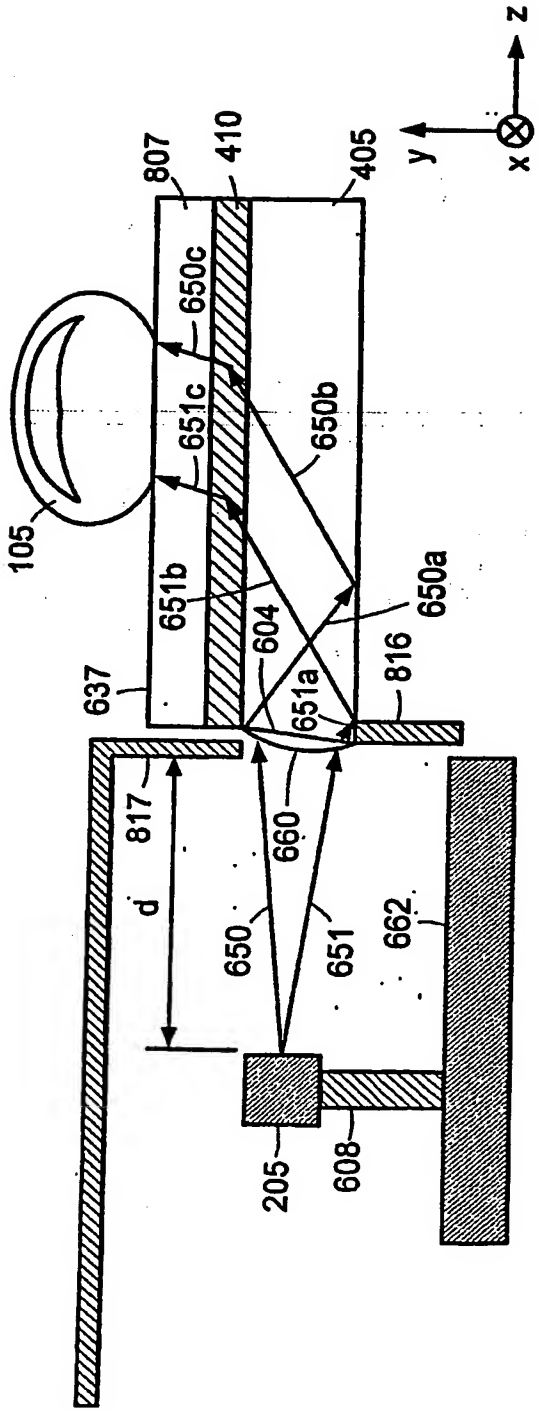

z
y
x
807
410
405
650c
651c
650b
105
651b
650a
604
816
637
651a
817
660
d
650
651
662
205
608

FIG. 6E

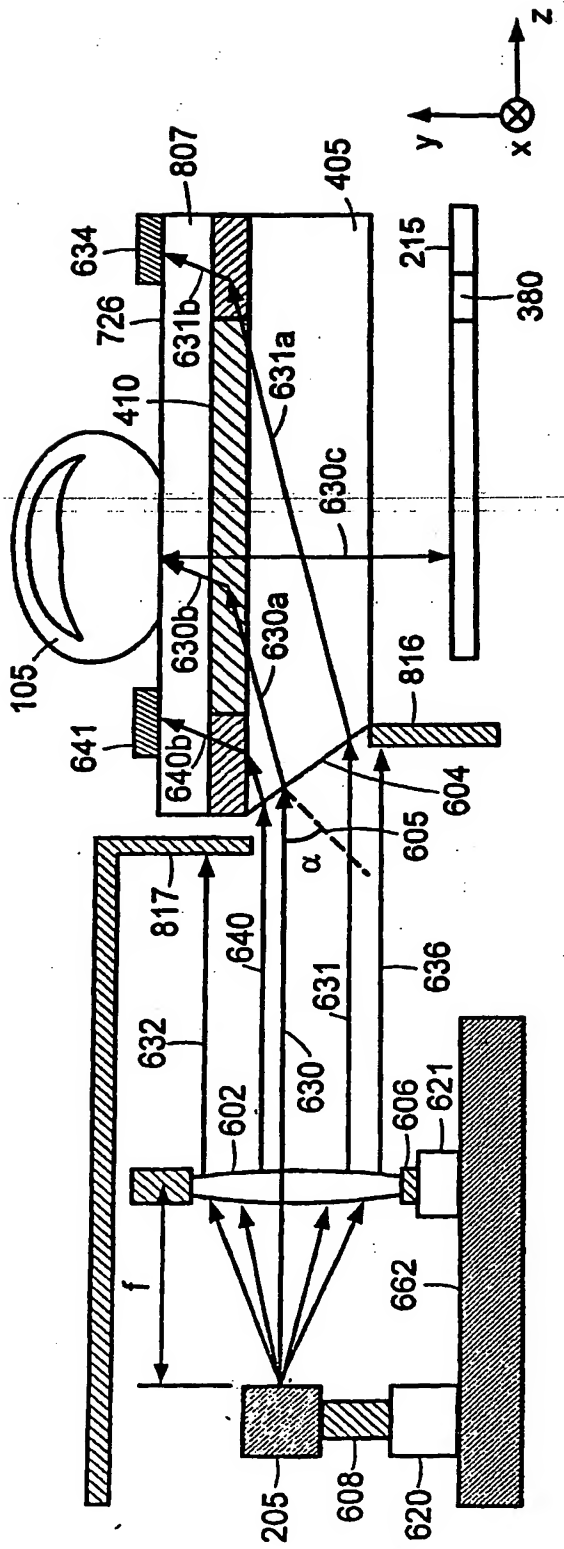

z
y
x
807
405
634
215
726
631b
631a
380
410
630c
630b
630a
105
816
641
640b
604
605
α
817
640
631
636
632
630
602
606
621
f
662
205
608
620

FIG. 7A

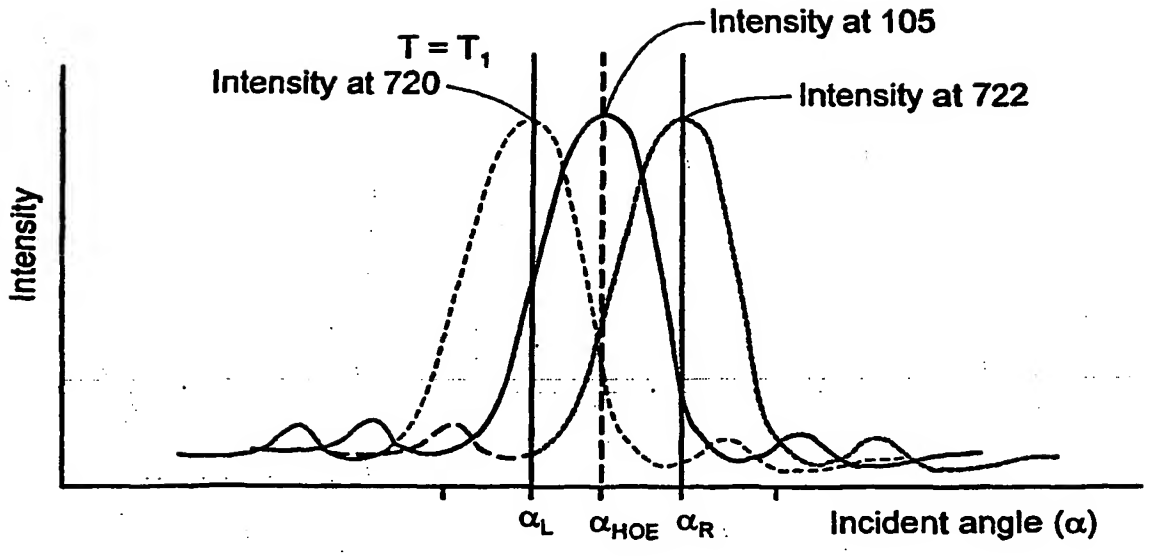

T = T1
Intensity at 720
Intensity at 105
Intensity at 722
Intensity
αL αHOE αR
Incident angle (α)

FIG. 7B

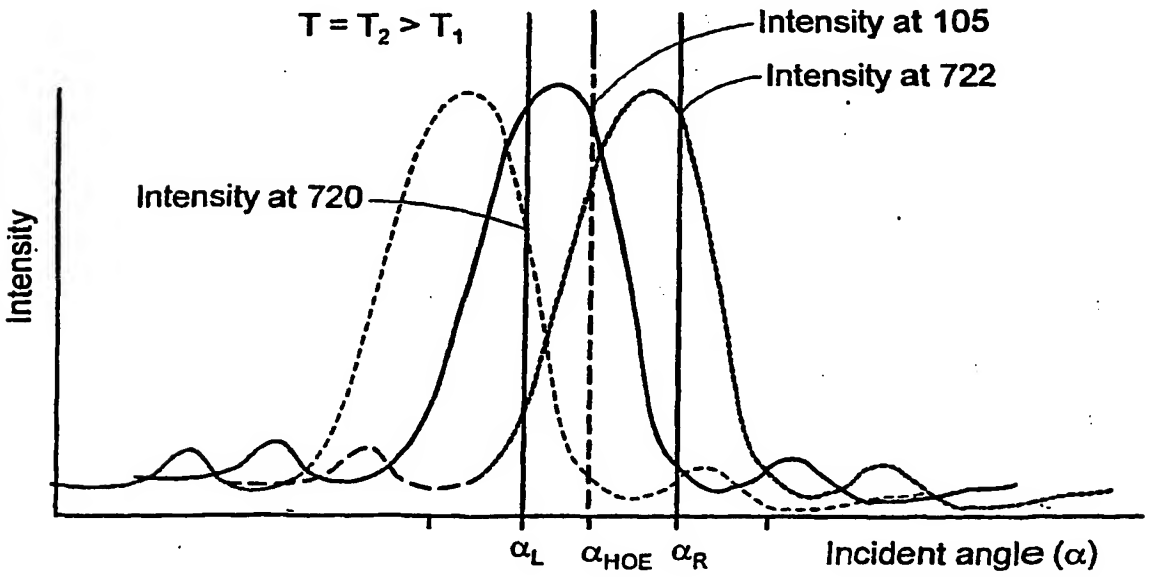

T = T2 > T1
Intensity at 105
Intensity at 722
Intensity at 720
Intensity
αL αHOE αR
Incident angle (α)

FIG. 7C

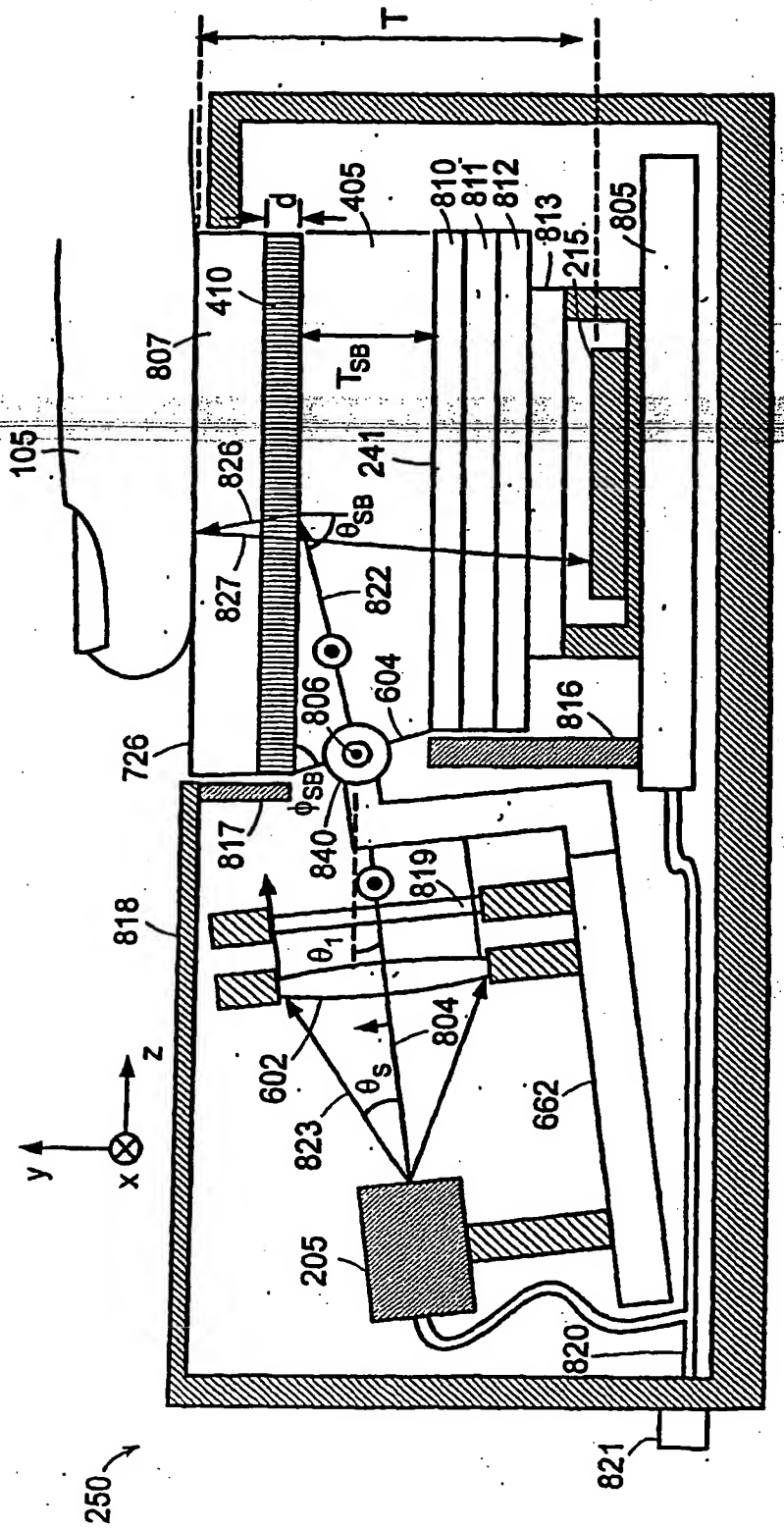

T
d
405
810
811
812
813
215
805
410
807
T_{SB}
105
826
241
θ_{SB}
827
822
604
806
816
726
ϕ_{SB}
817
840
819
818
θ_1
T
804
602
θ_s
662
823
z
y
x
205
820
821
250

FIG. 8A

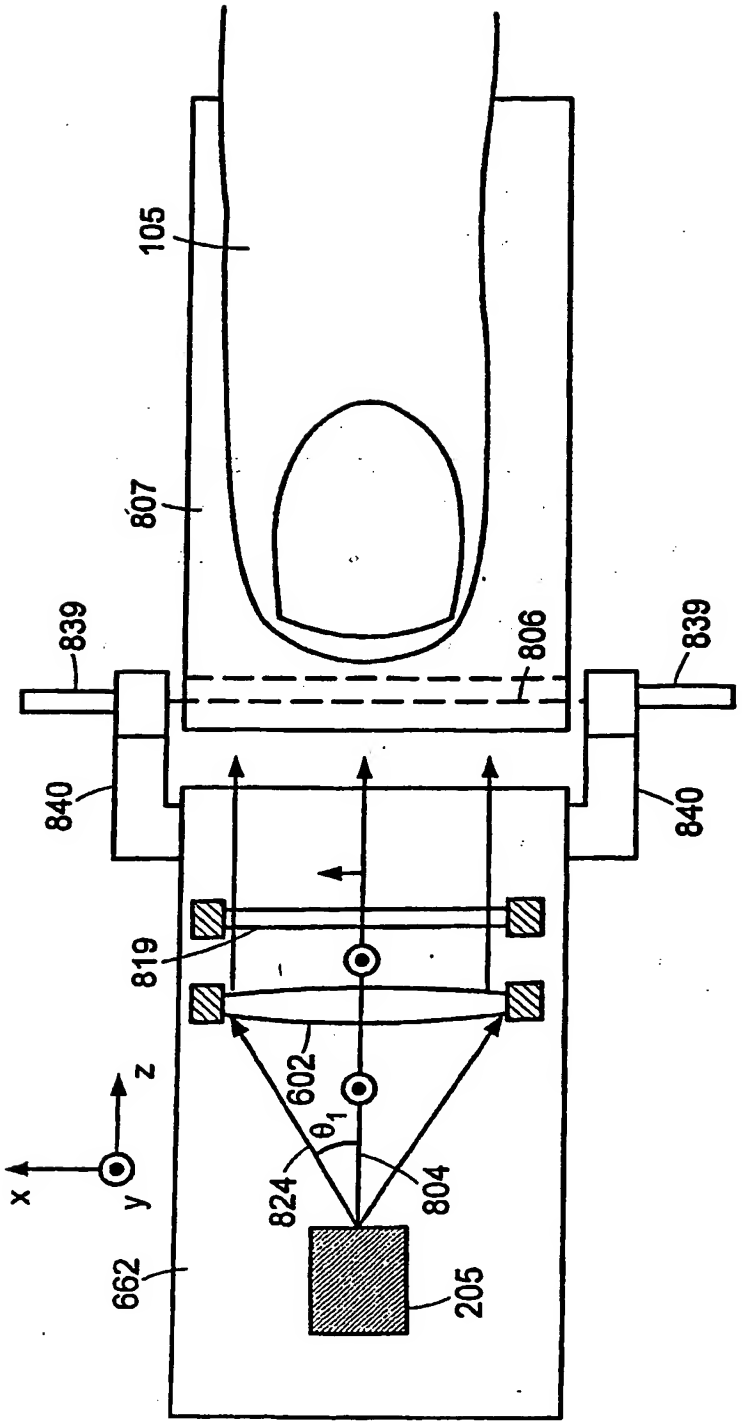


FIG. 8B

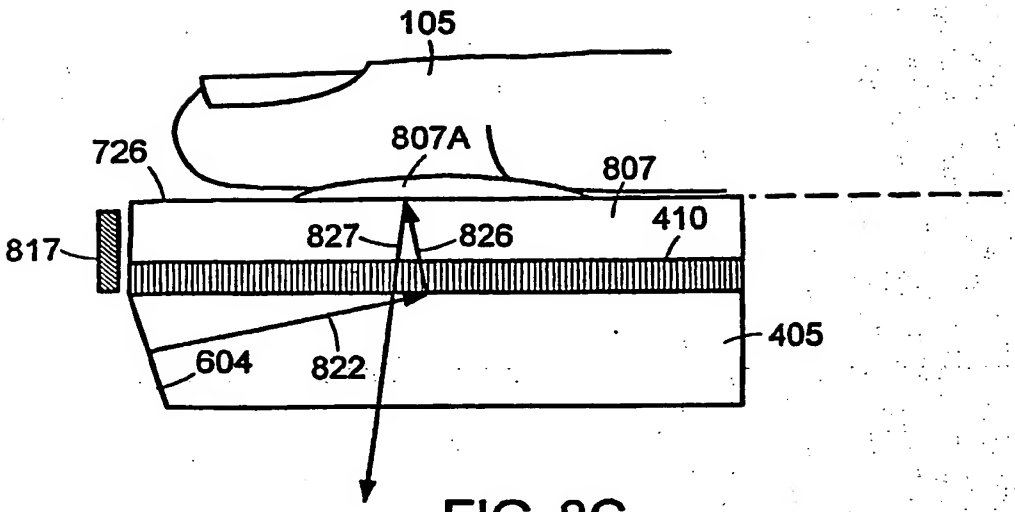

105
807A
726
807
410
827
826
817
405
604
822

FIG. 8C

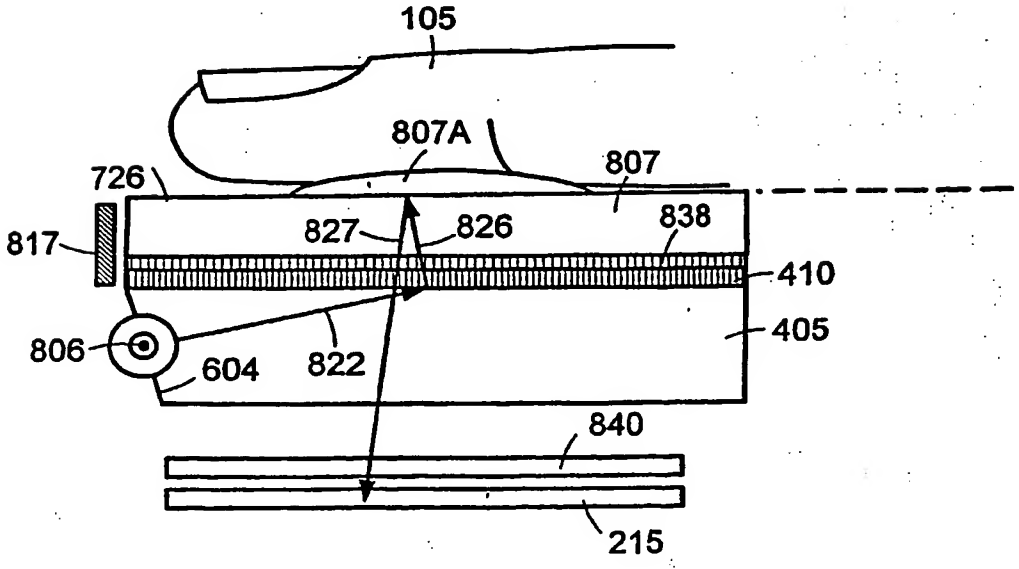

105
807A
807
726
838
827
826
817
410
405
806
604
822
840
215

FIG. 8D

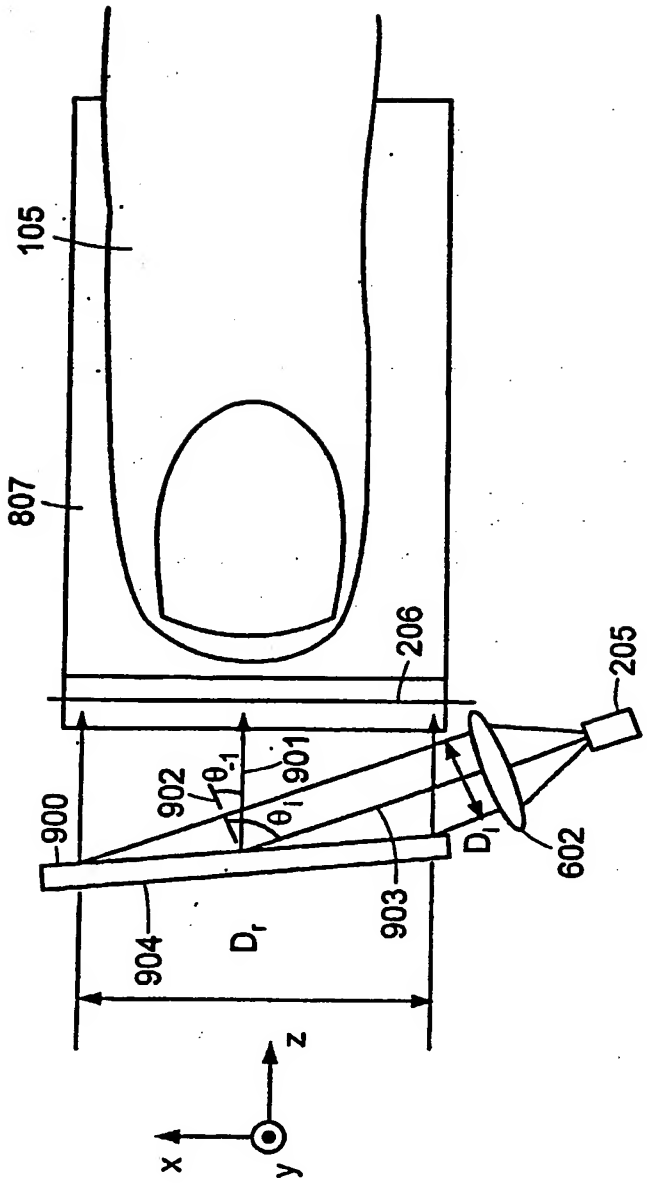


FIG. 9

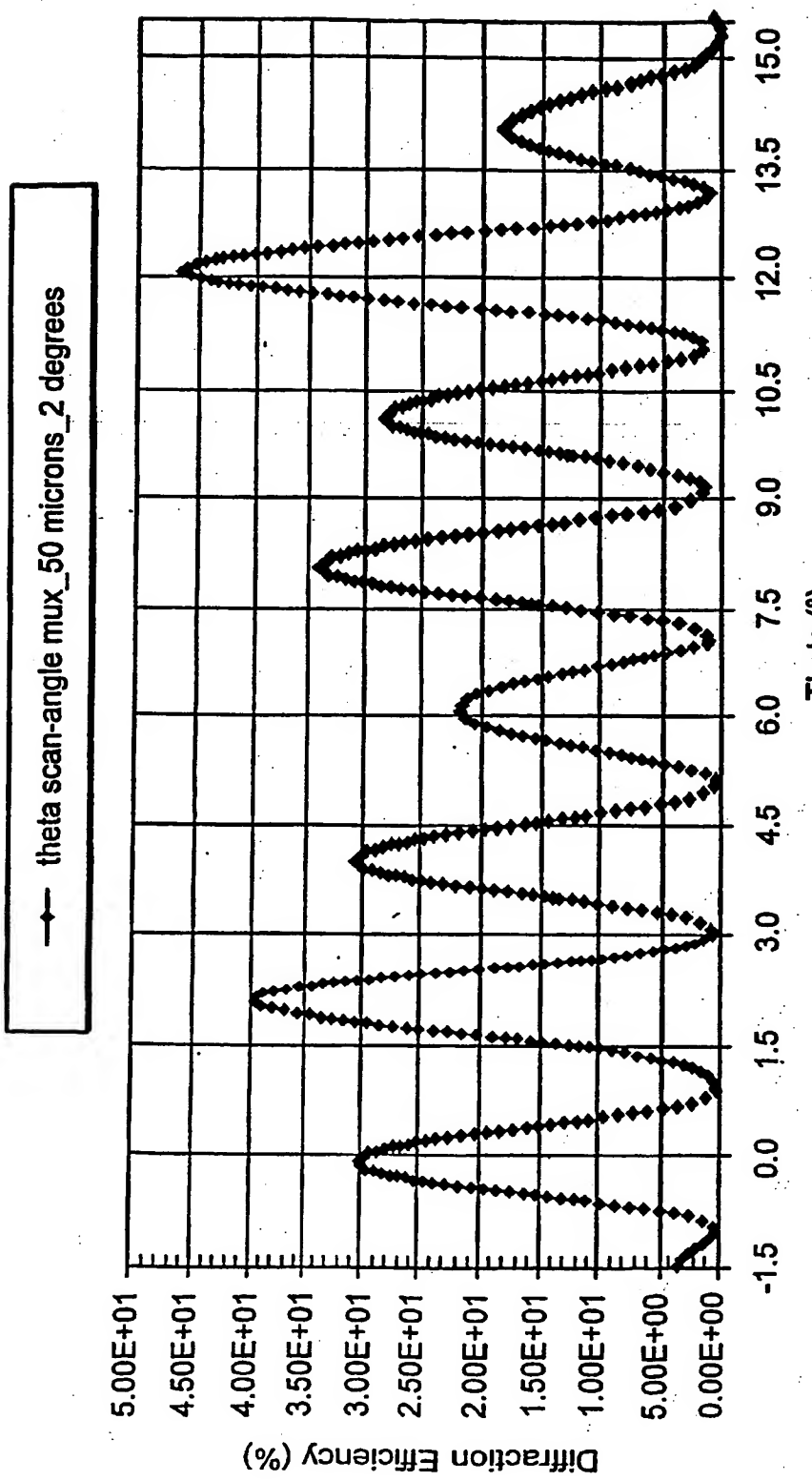

theta scan-angle mux_50 microns_2 degrees
Diffraction Efficiency (%)
5.00E+01
4.50E+01
4.00E+01
3.50E+01
3.00E+01
2.50E+01
2.00E+01
1.50E+01
1.00E+01
5.00E+00
0.00E+00
-1.5
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
Theta (°)

FIG. 10

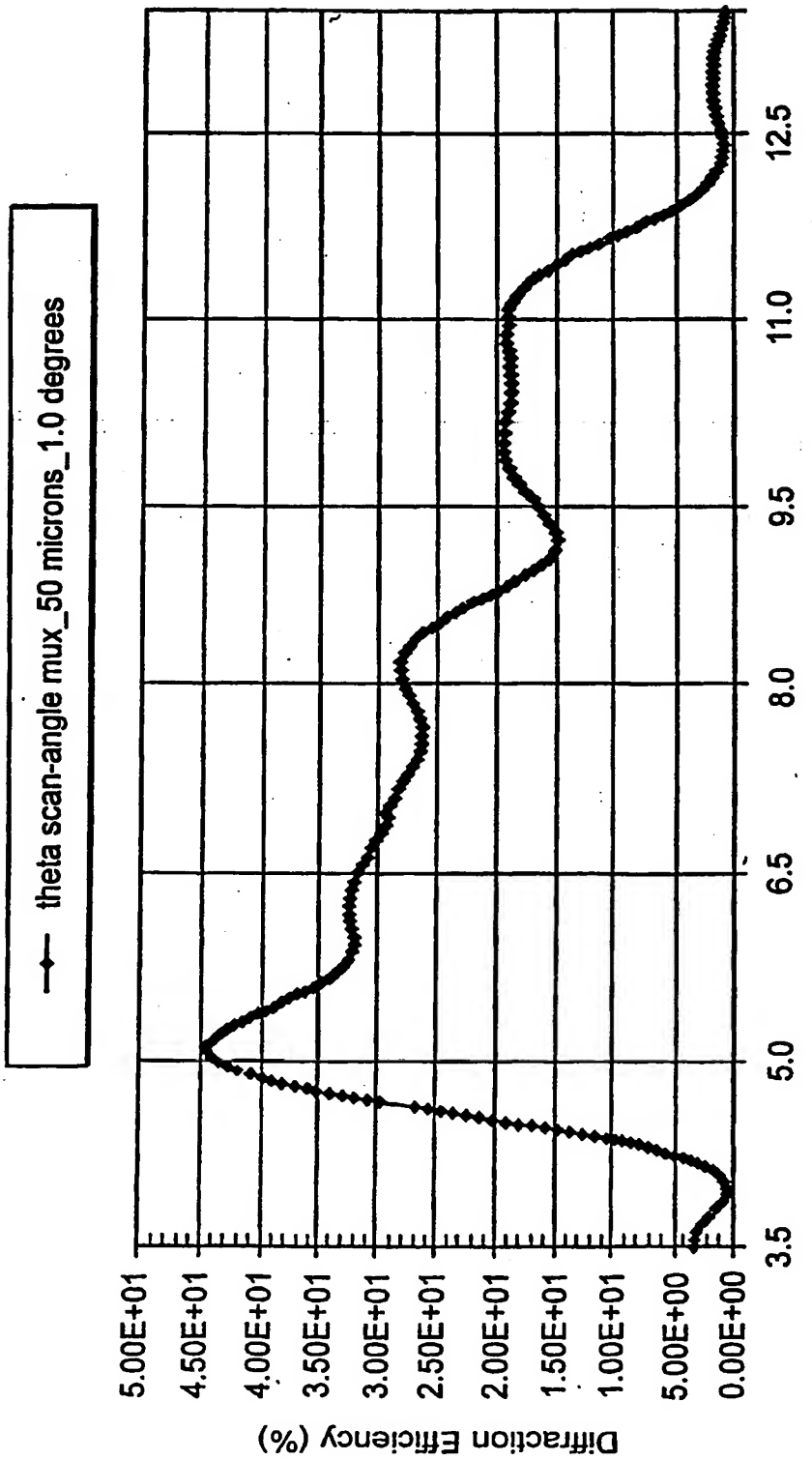

theta scan-angle mux_50 microns_1.0 degrees
Diffraction Efficiency (%)
5.00E+01
4.50E+01
4.00E+01
3.50E+01
3.00E+01
2.50E+01
2.00E+01
1.50E+01
1.00E+01
5.00E+00
0.00E+00
3.5
5.0
6.5
8.0
9.5
11.0
12.5
Theta (°)

FIG. 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/019917

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06K9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 061 463 A (PHILLIPS NICHOLAS J ET AL) 9 May 2000 (2000-05-09) column 9, lines 13-42	25,27-31
A	the whole document	1-24,26, 32-124
A	US 4 544 267 A (SCHILLER MICHAEL) 1 October 1985 (1985-10-01) the whole document	1-124
A	US 6 341 028 B1 (BAHUGUNA RAMENDRA D ET AL) 22 January 2002 (2002-01-22) the whole document	1-124

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 November 2004	23/11/2004

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Grigorescu, C

Form PCT/ISA/210 (second sheet) (January 2004)

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US2004/019917

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
US 6061463	A	09-05-2000	AT	195189 T	15-08-2000
			AU	1925595 A	04-09-1995
			DE	69518233 D1	07-09-2000
			EP	0749610 A1	27-12-1996
			JP	9509490 T	22-09-1997
US 4544267	A	01-10-1985	AT	32554 T	15-03-1988
			CA	1161250 A1	31-01-1984
			DE	3176657 D1	31-03-1988
			EP	0052348 A1	26-05-1982
US 6341028	B1	22-01-2002	US	6002499 A	14-12-1999
			US	5629764 A	13-05-1997
			US	5892599 A	06-04-1999
			US	6111671 A	29-08-2000
			AU	6542596 A	10-02-1997
			WO	9703412 A1	30-01-1997
			US	6038043 A	14-03-2000

Vincent Fedele
P.O. Box 061
Harvard, MA 01451-0061
U.S.A.

27 July, 2006

Beyer Weaver & Thomas, LLP
500 12th Street
Suite 200
Oakland, CA 94607

Subj: **Docket No. 3174.1012-013**

Dear Mr. Egan:

I am in receipt of your letter of 20 July, 2006 regarding the above-mentioned docket.

As you may be aware, I left Aprilis, Inc. on February 03, 2005. One-month prior on or about January 3rd I was provided with assignment and declaration documents by David Waldman for Docket No. 3174.1012-013, and took them immediately to Citizens Bank in Maynard, whose offices are on Nason Street, just outside of the Aprilis location. The documents were signed and notarized, and returned to David Waldman by hand in time to meet the mailing date for this application.

During several conversations with various officers of Aprilis during the week after my departure in February, Aprilis and Mr. Julio Vega, Counsel for Aprilis, confirmed that all assignments and declarations had been properly executed and received by the Company.

Any pertinent prior art, which I may have been aware of during the period I was employed by Aprilis, was disclosed at the time, and I am not aware of any other prior art for 3174.1012-013 since January of 2005.

An email message from Mr. Waldman in April or May of this year referred to several changes and or challenges made by the patent officer reviewing the file(s) that would require changes to one or both of the applications pending review. References to an other patent may also have been included, Docket No. 3174.1013-14. Neither patent application was provided, however, only assignment and declaration pages in Mr. Waldman's email message.

Since the assignment and or declaration documents, as well as your letter include statements that indicate I must read, review and understand the contents of the application(s), and since it has been several years since I have worked on these inventions, I will require at least a day or two to review them, and possibly some time

over the phone with Mr. Waldman. Please clarify if Docket No. 3174.1013-14 is also in need of assignment, declaration and requisite review, as it was not included in your package, but was mentioned in Mr. Waldman's email.

I am happy to provide such review(s), time permitting, as a consultant to the Company, and in accordance with my agreement with the Company which included a provision for compensation for such tasks. I estimate approximately one day, at a minimum, will be required to review the patent application you sent which appears to include more than one hundred claims and some seventy-five pages of text, figures and related documents.

I am planning travel and vacation during the next 2-3 weeks, if I do not hear back from you by August 8th, I will return the document package to your offices.

Regards,

Vincent Fedele

5. Inventions; Assignment.

(d) At the request of the Company, the Signatory will assist the Company in every proper way (including, without limitation, by executing patent applications) to obtain and enforce in any country in the world Proprietary Rights relating to any or all Assigned Inventions. The Signatory's obligation under this Section 5(d) shall continue after the termination of the Signatory's association with the Company as an employee, consultant, officer or director. If and to the extent that, at any time after the termination of the Signatory's association with the Company as an employee, consultant, officer and/or director, the Company requests assistance from the Signatory with respect to obtaining and enforcing in any country in the world any Proprietary Rights relating to Assigned Inventions, the Company shall compensate the Signatory at a reasonable rate for the time actually spent by the Signatory on such assistance.

BEYER WEAVER & THOMAS, LLP

INTELLECTUAL PROPERTY LAW

500 12th Street, Suite 200, Oakland, CA 94607
Telephone: (510) 663-1100 Facsimile: (510) 663-0920
www.beyerlaw.com

July 20, 2006

VIA CERTIFIED MAIL, RETURN RECEIPT REQUESTED

Mr. Vincent Fedele
P.O. Box 061
Harvard, MA 01451

Re: U.S. Patent Application Entitled: ***"Acquisition Of High Resolution Biometric Images"***
Inventors: David A. Waldman, et al.
Filing Date: December 20, 2005
Our File: VISGP001

Dear Mr. Fedele:

We represent Aprilis, Inc.

Enclosed is a copy of the above-identified patent application as filed with the U.S. Patent and Trademark Office. You may recall that the application was filed without having you sign the necessary documents (declaration and assignment forms) which should to be filed with the U.S. Patent and Trademark Office by **August 22, 2006** in order to avoid abandonment of the application.

Accordingly, we are enclosing two documents (i) a Declaration (ii) an Assignment of rights to Aprilis, Inc. Before executing these documents, please ensure that you have reviewed and understand the contents of the patent application. Then, read, sign and date each of the enclosed documents adjacent to where your name appears, and return them to our office, in the enclosed, self-addressed stamped envelope, **by August 18, 2006**, so that we may file them with the U.S. Patent and Trademark Office. Also, please note that your signature on the Assignment should be notarized.

Finally, we would again like to remind you of our duty to disclose the most pertinent prior art of which you are aware to the Patent and Trademark Office. If you can think of any pertinent references or patents, or any similar existing technology, please let us know. The duty to disclose prior art continues until the patent actually issues. As such, if you become aware of other prior art in the future, please let us know.

If you have any questions, please call.

Best regards,
BEYER WEAVER & THOMAS, LLP

William J. Egan, III

Enclosures

NO DOCKETING REQUIRED
WJE

Vincent Fedele
P.O. Box 061
Harvard, MA 01451-0061
U.S.A.

27 July, 2006

Beyer Weaver & Thomas, LLP
500 12th Street
Suite 200
Oakland, CA 94607

Subj: **Docket No. 3174.1012-013**

Dear Mr. Egan:

I am in receipt of your letter of 20 July, 2006 regarding the above-mentioned docket.

As you may be aware, I left Aprilis, Inc. on February 03, 2005. One-month prior on or about January 3rd I was provided with assignment and declaration documents by David Waldman for Docket No. 3174.1012-013, and took them immediately to Citizens Bank in Maynard, whose offices are on Nason Street, just outside of the Aprilis location. The documents were signed and notarized, and returned to David Waldman by hand in time to meet the mailing date for this application.

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An email message from Mr. Waldman in April or May of this year referred to several changes and or challenges made by the patent officer reviewing the file(s) that would require changes to one or both of the applications pending review. References to an other patent may also have been included, Docket No. 3174.1013-14. Neither patent application was provided, however, only assignment and declaration pages in Mr. Waldman's email message.

Since the assignment and or declaration documents, as well as your letter include statements that indicate I must read, review and understand the contents of the application(s), and since it has been several years since I have worked on these inventions, I will require at least a day or two to review them, and possibly some time

over the phone with Mr. Waldman. Please clarify if Docket No. 3174.1013-14 is also in need of assignment, declaration and requisite review, as it was not included in your package, but was mentioned in Mr. Waldman's email.

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Regards,

Vincent Fedele

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DOCKET NO. 3174.1012-013

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Declaration for Patent Application

[ ] Supplemental (37 C.F.R. §1.67)

As a named inventor, I hereby declare that:

My residence, mailing address and citizenship are as stated next to my name;

I believe I am the original, first and sole inventor (if only one name is listed) or an original, first and joint inventor (if plural names are listed in the signatory page(s) commencing at page 2 hereof) of the subject matter which is claimed and for which a patent is sought on the invention entitled

ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES

the specification of which (check one)

[ ] is attached hereto.

[ ] was filed on [ ] as United States Application Number [ ].

[X] was filed on June 21, 2004 as PCT International Application No. PCT/US2004/019917 and assigned United States Application No. 10/561,646.

[ ] and was amended on [ ] (if applicable).

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to patentability as defined in 37 C.F.R. §1.56, including for continuation-in-part applications, material information which became available between the filing date of the prior application and the national or PCT international filing date of the continuation-in-part application.

I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application.

I hereby claim foreign priority benefits under 35 U.S.C. 119 or 365 of any foreign application(s) for patent or inventor's certificate, or of any PCT international application which designated at least one country other than the United States of America, listed below and have also identified below, by checking the box, any foreign application for patent or inventor's certificate, or of any PCT international application having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s)			Priority Not Claimed	Certified Copy Filed? YES	NO
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]
(Number)	(Country)	(Day/Month/Year filed)	[ ]	[ ]	[ ]

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of **sole or first** inventor: David A. Waldman

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Concord	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: 31 Mitchell Road

City	State	ZIP	Country
Concord	MA	01742	USA

Full name of **second** joint inventor, if any: Vincent Fedele

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Harvard	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: P.O. Box 061

City	State	ZIP	Country
Harvard	MA	01451	USA

Full name of **third** joint inventor, if any: Richard T. Ingwall

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Newton	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: 115 Dartmouth Street

City	State	ZIP	Country
Newton	MA	02465	USA

Full name of **fourth** joint inventor, if any: Daniel H. Raguin

Inventor's Signature: _____

Residence: City	State	Country	Citizenship
Acton	MA	USA	USA

Mailing Address (Business or Residential)

Street or P.O. Box: 234 Newtown Road

City	State	ZIP	Country
Acton	MA	01720	USA

Full name of **fifth** joint inventor, if any John S. Berg

Inventor's Signature

Residence: City	State	Country	Citizenship
Franklin	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box 58 Jefferson Road

City	State	ZIP	Country
Franklin	MA	02038-3360	USA

Full name of **sixth** joint inventor, if any Joby Joseph

Inventor's Signature

Residence: City	State	Country	Citizenship
New Delhi		India	India

Mailing Address (Business or Residential)
Street or P.O. Box 34 Vaishali Apt., I.I.T. Delhi

City	State	ZIP	Country
New Delhi		110016	India

Full name of **seventh** joint inventor, if any David L. Kent

Inventor's Signature

Residence: City	State	Country	Citizenship
Framingham	MA	USA	USA

Mailing Address (Business or Residential)
Street or P.O. Box 10 Frost Street

City	State	ZIP	Country
Framingham	MA	01701	USA

Docket No. 3174.1012-013

Joint

ASSIGNMENT

WHEREAS, we, **David A. Waldman, Vincent Fedele, Richard T. Ingwall, Daniel H. Raguin, John S. Berg, Joby Joseph and David L. Kent**, have invented a certain improvement in **ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES** described in an application for Patent,

[ ] the specification of which is about to be filed in the United States Patent Office *(use for utility (37 CFR § 1.53(b)) and design filings only)*;

[ ] is about to be filed in the United States Patent Office as a Provisional Application;

[ ] the specification of which is United States Application No. [ ], filed [ ];

[X] the specification of which is a Patent Cooperation Treaty Application, International Application No. **PCT/US2004/019917**, filed **June 21, 2004**, which designates the United States of America and assigned United States Application No. **10/561,646**;

[ ] which was patented under United States Patent No. [ ].

WHEREAS, **Aprilis, Inc.** (hereinafter "ASSIGNEE"), a corporation organized and existing under the laws of the **State of Delaware**, and having a usual place of business at **5 Clock Tower Place, Suite 200, Maynard, Massachusetts 01754** desires to acquire an interest therein in accordance with agreements duly entered into with us;

NOW, THEREFORE, to all whom it may concern be it known that for and in consideration of said agreements and of other good and valuable consideration, the receipt of which is hereby acknowledged, we have sold, assigned and transferred and by these presents do hereby sell, assign and transfer unto said ASSIGNEE, its successors, assigns and legal representatives, the entire right, title and interest in and throughout the United States of America, its territories and all foreign countries, in and to said invention as described in said application, together with the entire right, title and interest in and to said application and such Letters Patent as may issue on said invention; said invention, application and Letters Patent to be held and enjoyed by said ASSIGNEE for its own use and behalf and for its successors, assigns and legal representatives, to the full end of the term for which said Letters Patent may be granted as fully and entirely as the same would have been held by us had this assignment and sale not been made; we hereby convey all rights arising under or pursuant to any and all international agreements, treaties or laws relating to the protection of industrial property by filing any such applications for Letters Patent. We hereby acknowledge that this assignment, being of the entire right, title and interest in and to said invention, carries with it the right in ASSIGNEE to apply for and obtain from competent authorities in all countries of the world any and all Letters Patent by attorneys and agents of ASSIGNEE's selection and the right to procure the grant of all such Letters Patent to ASSIGNEE for its own name as assignee of the entire right, title and interest therein; I hereby expressly authorize the filing of an International Patent Application under the Patent Cooperation Treaty which corresponds to and claims the priority of the above-identified application;

AND, we hereby further agree for ourselves and our executors and administrators to execute upon request any other lawful documents and likewise to perform any other lawful acts which may be deemed necessary to secure fully the aforesaid invention to said ASSIGNEE, its successors, assigns and legal representatives, but at its or their expense and charges, including the execution of applications for patents in foreign countries, and the execution of any future applications including substitution, reissue, divisional or continuation applications, and preliminary or other statements and the giving of testimony in any interference or other proceeding in which said invention or any application or patent directed thereto may be involved;

AND, we do hereby authorize and request each Patent Office and the Commissioner of Patents of the United States to issue such Letters Patent as shall be granted upon said invention to said ASSIGNEE, its successors, assigns, and legal representatives.

IN TESTIMONY WHEREOF, we have hereunto set our hands and affixed our seals the date set forth below.

Inventor's Signature: _____

David A. Waldman

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **David A. Waldman**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was

_____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

Vincent Fedele

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Vincent Fedele,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

Richard T. Ingwall

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Richard T. Ingwall,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

Daniel H. Raguin

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Daniel H. Raguin,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____
John S. Berg

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **John S. Berg,**

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

Inventor's Signature: _____

Joby Joseph

State/Commonwealth

of _____

County of _____

On this _____ day of _____, 20_____, before me, the undersigned notary public, personally appeared **Joby Joseph**,

☐ personally known to me, or

☐ proved to me through satisfactory evidence of identification, which was _____

to be the person whose name was signed on the foregoing instrument in my presence, and acknowledged that he/she signed the foregoing instrument as his/her free act and deed.

(SEAL) _____ Notary Public

_____ (print name)

My Commission expires _____/_____/_____

WO 2005/001753
PCT/US2004/01991

SAW

PATENT COOPERATION TREATY

From the INTERNATIONAL BUREAU

PCT

NOTIFICATION CONCERNING TRANSMITTAL OF COPY OF INTERNATIONAL APPLICATION AS PUBLISHED OR REPUBLISHED

To:

MEAGHER, Timothy, J.
Hamilton, Brook, Smith & Reynolds, P.C.
530 Virginia Road
P.O. Box 9133
Concord, MA 01742-9133
ETATS-UNIS D'AMERIQUE

Date of mailing *(day/month/year)* 06 January 2005 (06.01.2005)	
Applicant's or agent's file reference 3174.1012004	**IMPORTANT NOTICE**

International application No.	International filing date *(day/month/year)*	Priority date *(day/month/year)*
PCT/US2004/019917	21 June 2004 (21.06.2004)	21 June 2003 (21.06.2003)

Applicant: APRILIS, INC. et al

The International Bureau transmits herewith the following documents:

☑ copy of the international application as published by the International Bureau on 06 January 2005 (06.01.2005) under No. WO 2005/001753

☐ copy of international application as republished by the International Bureau on under No. WO
For an explanation as to the reason for this republication of the international application, reference is made to INID codes (15), (48) or (88) (*as the case may be*) on the front page of the attached document.

The International Bureau of WIPO 34, chemin des Colombettes 1211 Geneva 20, Switzerland	Authorized officer Simin Baharlou
Facsimile No.+41 22 740 14 35	Facsimile No.+41 22 338 71 30

3174.1012-004

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
6 January 2005 (06.01.2005)

PCT

(10) International Publication Number
WO 2005/001753 A1

(51) International Patent Classification[7]: G06K 9/00

(21) International Application Number:
PCT/US2004/019917

(22) International Filing Date: 21 June 2004 (21.06.2004)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:

60/480,008	21 June 2003 (21.06.2003)	US
60/519,792	13 November 2003 (13.11.2003)	US
60/523,068	18 November 2003 (18.11.2003)	US

(71) Applicant *(for all designated States except US)*: **APRILIS, INC.** [US/US]; 5 Clock Tower Place, Suite 200, Maynard, MA 01754 (US).

(72) Inventors; and

(75) Inventors/Applicants *(for US only)*: **WALDMAN, David** [US/US]; 31 Mitchell Road, Concord, MA 01742 (US). **FEDELE, Vincent** [US/US]; Post Office Box 061, Harvard, MA 01451 (US). **INGWALL, Richard, T.** [US/US]; 115 Dartmouth Street, Newton, MA 02465 (US). **RAGUIN, Daniel, H.** [US/US]; 234 Newtown Road, Acton, MA 01720 (US). **BERG, John, S.** [US/US]; 58 Jefferson Road, Franklin, MA 02038 (US). **JOSEPH, Joby** [IN/US]; Waltham, MA 02453 (US). **KENT, David, L.** [US/US]; 10 Frost Street, Framingham, MA 01701 (US).

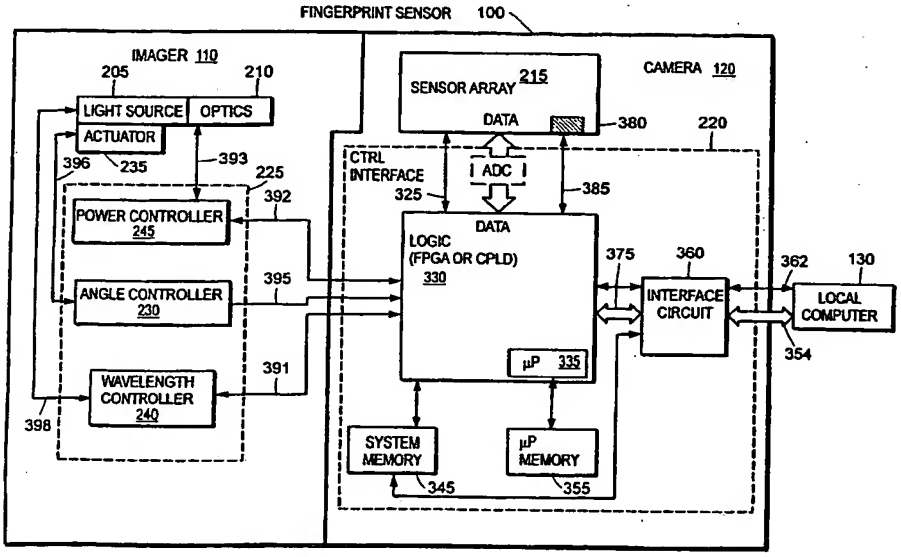
(74) Agents: **MEAGHER, Timothy, J.** et al.; Hamilton, Brook, Smith & Reynolds, P.C., 530 Virginia Road, P.O. Box 9133, Concord, MA 01742-9133 (US).

(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BW, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NA, NI, NO, NZ, OM, PG, PH, PL, PT, RO, RU, SC, SD, SE, SG, SK, SL, SY, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, YU, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH,

[Continued on next page]

(54) Title: ACQUISITION OF HIGH RESOLUTION BOIMETRIC IMAGES



(57) Abstract: An apparatus for image acquisition of topological features of the surface of skin. The apparatus comprises a waveguide, having an entrance edge and top and bottom surfaces; a light source, configured to direct a light beam at the entrance edge of the waveguide; a skin contact layer, disposed at or near the top surface of the waveguides; a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer; a sensor array, configured to detect light reflected from the surface of skin in contact with skin contact layer; and means for compensating for changes in the Bragg matching condition of the HOE due to temperature.

WO 2005/001753 A1

ACQUISITION OF HIGH RESOLUTION BIOMETRIC IMAGES

RELATED APPLICATIONS

This application claims the benefit of U.S. Provisional Application No. 60/480,008, filed on June 21, 2003, U.S. Provisional Application No. 60/519,792, filed on November 13, 2003 and U.S. Provisional Application No. 60/523,068, filed on November 11, 2003. This application is related to the PCT Application entitled "Method and Apparatus for Processing Biometric Images" filed concurrently herewith on June 21, 2004 under the attorney docket number 3174.1012-006. The entire teachings of the above applications are incorporated herein by reference.

BACKGROUND OF THE INVENTION

Growing concerns regarding domestic security have created a critical need to positively identify individuals as legitimate holders of credit cards, driver's licenses, passports and other forms of identification. The ideal identification process is reliable, fast, and relatively inexpensive. It should be based on modern high-speed electronic devices that can be networked to enable fast and effective sharing of information. It should also be compact, portable, and robust for convenient use in a variety of environments, including airport security stations, customs and border crossings, police vehicles, home and office computing and entrance control sites of secure buildings.

A well established method for identification is to compare a fingerprint with a previously obtained authentic fingerprint of the individual. Fingerprints have traditionally been collected by rolling an inked finger on a white paper. Since this traditional process clearly fails to meet the criteria listed above, numerous attempts have been made to adapt an electronically imaged fingerprint method to address new security demands. These modern proposals all use, as a key component, a solid-state device such as a capacitive or optical sensor to capture the fingerprint image in a digital format. By using a new type of solid-state imager as part of a fingerprint

with a few minutiae points can positively identify an individual reliably.

Most optical designs proposed for creating fingerprint images suffer important limitations that reduce their usefulness in real life applications. Many designs are not suitable, for example, to resolve pore patterns or fine detail of the contour of the intersection of ridges and valleys in the fingerprint. Other designs produce distorted images that complicate fingerprint correlation, and still other designs are too bulky or delicate for convenient use in the field.

One optical design that reduces the overall size of the device uses holograms to diffract light in a desired direction. A common limitation of such devices is sensitivity of the intensity of illumination of the target topological surface to variation in temperature with respect to angle and wavelength of the incident light. Accordingly, there is a need for a compact, high resolution device that reliably operates over a broad range of temperature.

SUMMARY OF THE INVENTION

The present invention relates to an apparatus and method of acquisition of an image of any surface topology present on skin, which, by way of example, can be a rolled and/or slap fingerprint, palm print, etc. and hereinafter for convenience will be referred to as a fingerprint.

In one embodiment, the present invention is an apparatus for fingerprint image acquisition, comprising a waveguide, having an entrance edge and top and bottom; a light source, configured to direct a light beam at the entrance edge of the waveguide; a skin contact layer, disposed at or near the top surface of the waveguide or bottom surface of the waveguide; a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer; a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer. The HOE includes a layer comprising a grating and at least one supporting layer in contact with the said grating layer, wherein the grating layer and the at least one supporting layer have substantially similar coefficients of thermal expansion or thermo-optic coefficients or both.

light beam at the entrance edge of the waveguide; a skin contact layer, disposed at the top surface of the waveguide; a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam at the skin contact layer and having a Bragg matching condition; a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer, and means for compensating for changes in the Bragg matching condition of the HOE due to changes in temperature. The light source is a broad wavelength spectrum light source, the wavelengths of which can reconstruct the HOE.

In one embodiment, the present invention is a method of acquiring an image of the topology of the surface of skin, comprising receiving a surface of skin by a device for image acquisition of the topological features of the surface of skin wherein said device includes a holographic optical element (HOE) having a Bragg matching condition; directing a light beam at the HOE, thereby diffracting the light beam; directing the diffracted light beam at the interface between skin and the skin contact layer, thereby reflecting the light beam; compensating for temperature-induced changes in the Bragg matching condition of the HOE; and detecting the reflected light, thereby acquiring the image of the topological features of the surface of skin by said device.

It should be understood that the example embodiments described above, include a corresponding method or apparatus embodiments.

The device of the present invention is preferably compact, possesses a broad operating temperature range and advantageously allows the acquisition of images that capture pore structural features and fine detail features of the contour of the ridge structure in addition to standard minutiae structures. We have shown that the use of pores combined with the use of the fine detail of the ridge contour and the usual minutiae significantly increases the reliability of fingerprint comparisons, and substantially reduces the false accept rate, as well as providing positive identification with use of fingerprint sample areas as small as 0.1 x 0.1 inches.

Various example embodiments of the instrument used to acquire images of biometrics are described herein. The embodiments may also include alternative embodiments of the instrument and various embodiments of acquiring, modeling,

DETAILED DESCRIPTION OF THE INVENTION

A description of preferred embodiments of the invention for a fingerprint biometric follows. It should be understood that the principles of the present invention and example preferred embodiments of the methods and apparatus described below may be applied to other biometrics, including: ear shape and structure, facial or hand thermograms, iris or retina structure, handwriting, fingerprints, palm prints, foot prints, toe prints, or prints of other areas of the skin, including hair.

FIG. 1 is a system diagram in which an embodiment of a fingerprint sensor according to the principles of the present invention is employed. The fingerprint sensor 100 includes a fingerprint imager 110 and fingerprint camera 120. The imager 110 and camera 120 may be mechanically, electrically, and optically connected in a single "box." A finger 105 or other topological surface of skin is placed on the fingerprint imager 110 at a "viewable" location by the imager 110 for acquisition of a fingerprint or information of other topological surfaces of skin 115 by the camera 120 and for modeling of the fingerprint 115 by processing as described in co-pending PCT application with attorney docket number 3174.1012-006 filed concurrently herewith on June 21, 2004.

Continuing to refer to FIG. 1, the fingerprint camera 120 includes an interface to communicate bidirectionally with a local computer 130 via a control channel/data link 125. The fingerprint camera 120 sends image data 160 to the local computer 130, and the local computer 130 may send control data 165 or other information, including image data 125, to the fingerprint camera 120 or imager 110 via the link 125.

The local computer 130 includes a variety of processing capabilities, such as modeling, authentication, and authorization that are applied to the image data 160. The local computer 130 is in communication with a local database 135 via a local link 132. Image data and associated model(s) 170, collectively, are communicated between the local computer 130 and local database 135 via the local link 132. Other data, such as administrative data, may also be communicated over the local link 132 for storage in the local database 135 for later retrieval.

that are available with fully proportional-integral-derivative feedback for closed loop control (second wavelength adsorber within HOE).

FIG. 2 is a hierarchical diagram of the fingerprint sensor 100. The fingerprint sensor 100, as discussed in reference to FIG. 1, includes a fingerprint imager 110 and fingerprint camera 120. Each will be discussed in turn.

The fingerprint imager 110 includes a light source 205, optics 210, and, optionally, active control circuits/element(s) 225. The light source 205 may be a coherent light source, such as a laser diode, which works efficiently with a HOE, or may be a non-coherent light source. The optics 210 includes optical elements 250, which are non-HOE's such as a slab waveguide, waveplate, polarizer, and lens(es), and at least one HOE, labeled 255 in FIG. 2, which includes a hologram.

The optional active control circuit/element(s) 225 may include an angle controller 230 and actuator 235. The actuator may be Direct Current (DC) motor, stepper motor, piezo-electric actuator, or other electro-mechanical device capable and adaptable for use in moving the light source 205 to positions and/or at angles fine enough for use in the fingerprint sensor 100. A wavelength controller 240 may also be employed in the imager 110, where the wavelength controller 240 may be used to change the wavelength of the light source 205, which, in turn, can compensate for temperature-induced changes in the angle for the Bragg matching condition of the HOE. A power controller 245 may also be employed by the imager 110 to control the output power and/or wavelength of the light source 205 for controlling exposure levels of the fingerprint 115.

The fingerprint camera 120 includes a sensor array 215 and electronics 220. The sensor array 215 may be a Charge Coupled Device (CCD) or Complimentary Metal Oxide Semiconductor (CMOS) and have a plurality of pixels arranged in a rectangular, or square pattern or other suitable pattern, providing a resolution fine enough for use in the fingerprint sensor 100. The electronics 220 are coupled to the sensor array 215 for receiving pixel data for processing. The electronics may include, by way of example, a processor, memory, A/D conversion, circuitry for variable shutter and/or integration time, and sensor data communications interface.

difference in actual signal level and a desired signal level corresponding to imaging performance.

For example, in the case of the fingerprint sensor 100, the feedback signal 395 may represent an angular error (i.e. mismatch from the Bragg matching condition of the HOE for light of a particular wavelength incident to the HOE) of the light beam emitting from the light source 205 and projecting onto the topological surface of the fingerprint, which may be caused by temperature effects on the optics 210. The camera logic 330 or microprocessor 335 may determine the feedback signal 395 based on the image data from the sensor array 215. The image data provided by the sensor array 215, for the purposes of feedback control, may include intensity data from a specific pixel in the sensor array, or data from a grouping of pixels in the sensor array or any combination thereof, or said image data used for feedback control may originate from at least one separate and independent sensor 386, providing signal 387 to camera electronics 220 for feedback control, that may comprise a plurality of sensors. The sensor array 215 may contain an additional light sensitive area 380, separate from the array of imaging pixels in the sensor array 215 and comprising one or more pixel, which may provide a signal 385 to the camera electronics 220 for the purposes of feedback control.

The camera electronics 220 may also provide a control signal 325 to the sensor array 215 for use during imaging of the fingerprint features or other topological features of the skin surface. The camera electronics may further include system memory 345 for storing image data following acquisition. The system memory 345 may also provide support for storing image data or partial image data during processing of the fingerprint image. The camera electronics 220 may further include microprocessor memory 355 for supporting the microprocessor 335. The microprocessor 335 and associated memory 355 may be used, for example, for processing the image data or calculating the feedback parameters in order to determine feedback signals 391, 392 or 395 or combinations thereof. Further, the camera electronics 220 may also include an interface circuit 360 for communicating with the local computer 130 via the communications link for transferring the image data 125 and fingerprint sensor control information 165 (see FIG. 1). The interface

curved surface may be a cone, and a subject whose palm print is taken places his or her palm wrapped around the outer surface of the cone. In another embodiment, the waveguide is a cone having an inner surface accessible and a subject placing his or her finger in contact with such inner surface. Accordingly, as used herein, the term "top waveguide surface" generally refers to the skin-proximal surface of the waveguide, i.e. the surface in contact with skin. As used herein, the term "bottom waveguide surface" refers to the sensor array-proximal surface of the waveguide, i.e. the surface opposite to the skin proximal surface.

Use of holographic optical elements (HOE) that comprise a photopolymer recording media attached to at least one support layer allows for a compact design without sacrificing resolution. However, certain important characteristics of the holographic optical element are very temperature sensitive. For transmission holograms, such as illustrated in FIG. 5, the fraction of light diffracted by the hologram depends both on the wavelength of the light, and its angle of incidence θ at the interface between HOE 410 and waveguide 405. Adequate diffraction efficiency occurs only in narrow wavelength and angular ranges that are determined by the angles of the recording conditions for the HOE, the thickness of the hologram medium, and the wavelength of the light used for recording the HOE (collectively determine so called Bragg selectivity or Bragg matching condition), and the wavelength of the light used to reconstruct the HOE. Without appropriate adjustments to the wavelength or incident angle, temperature changes of only a few degrees will significantly reduce or even eliminate holographic diffraction of a single hologram due to the effect of temperature on the refractive index of the hologram, the grating spacing and the grating angle.

Referring to FIG. 5, the intensity of diffracted light at temperature $T = T_1$ has a peak at an incident angle θ_1 to the HOE for a specific wavelength λ_1. As temperature changes from $T = T_1$ to $T = T_2$ to $T = T_3$, the peak of intensity of diffracted light at a fixed location along the z-axis shifts from an incident angle θ_1 to an incident angle of θ_2 to an incident angle θ_3, for a fixed incident wavelength λ_1. As a result, intensity of light diffracted to a fixed location z_0 along the z-axis decreases, thus significantly degrading the signal-to-noise (SNR) ratio. Similarly as

of beam 207 changes from α_1 to α_2 at entrance edge 604 when T changes from $T=T_1$ to $T=T_2$. It may be shown that the following relationship for holds true:

$$\alpha_2 - \alpha_1 = \frac{CTE_d L_1 - CTE_l L_3}{f} \Delta T, \qquad (1)$$

where $\Delta T = T_2 - T_1$, and CTE_d and CTE_l are the coefficients of thermal expansion for the light source (e.g., laser diode) mount and for the lens mount, respectively.

It is understood that a material that expands as temperature increases preferably also contracts as temperature decreases or vica versa. Thus, as used herein, the term "thermally expandable" means changing volume or length with temperature.

Alternate embodiments of this general concept include, but are not limited to, translating the lens element 602 in the y-direction, tilting waveguide 405 in the y-z plane, and/or moving and tilting a light source 205 provided that light source 205 outputs a collimated beam. In this latter embodiment, lens element 602 is integrated into the light source 205. These motions can all be achieved automatically via temperature induced changes in the dimensions of the structural elements that form the mechanical mounts for these optical components. These motions can be performed in any combination and those skilled in the art will be able to choose proper materials and dimensions for said mechanical mounts.

Referring back to FIG. 3 and to FIG. 6C and the inset, the fingerprint apparatus of this invention further comprises an electronically controlled actuator 390, such as a motor, that can be used to adjust the angle of incidence α by changing the vertical position of the lens element 602 with respect to the optical axis of light source 205, or by changing the vertical position of the light source 205 with respect to the optical center of lens element 602, such as shown in FIG 6C inset by vertical translation of the light source to a height position of $y = \Delta y$ at $T=T_2$. As depicted in FIG. 6C, the electronic actuator is represented by two separate motors 620 and 621 that drive the laser source 205 and the lens element 602, respectively in the y-direction to accommodate changes in incident angles at the entrance edge 604. There is a number of means by which the signal to drive the actuator can be obtained by one skilled in the art, and the methods depicted in FIG. 6C and its inset are intended to be illustrative but not limiting. In particular, it is desirable to use light diffracted

locations where its path of internal reflection is terminated by the presence of another surface, such as edge 690 of waveguide 405.

Alternatively, a second hologram, as well be detailed further in reference to the description of FIG. 7A, included specifically for the purpose of generating a servo feedback signal, can be recorded so as to be located in the vicinity of the main hologram of HOE 410. In one embodiment, this second hologram can be co-located with the main hologram by being co-locationally multiplexed.

Referring to FIG. 6D additional embodiments of the device of the present invention are shown. Specifically, entrance edge 604 is designed so that the incident ray 630 refracts as ray 630a towards bottom surface 612 of the waveguide 405. A portion of bottom surface 612 of waveguide 405 can be coated with a reflective layer (*e.g.* metal coating) labeled 614. Reflective layer 614 operates to protect waveguide 405 from smudges and other defects or contamination that may arise on bottom surface 612. These defects, if present, can add aberrations and regions of non-uniform beam intensity in the reflected beam 630e, such as by suppressing total internal reflection at locations of the defects, thereby possibly compromising the quality of the image collected by sensor array 215. It is preferable that reflective layer 614 only extend as far as would be required to protect the area of the first reflection of the incident light at surface 612. The extent of reflective layer 614 the z-direction should not block rays such as ray 630d from reaching sensor array 215.

In another embodiment waveguide 405 includes light traps 655 at edge 690, see FIG. 6D. Light traps 655 are designed to absorb substantially all of the light incident upon edge 690 and allow a minimum of light to reflect at edge 690. Suppressing such reflections (for example ray 630e that is undiffracted by HOE 410) minimizes the amount of spurious light that may illuminate the skin topology under examination and/or the amount of spurious light that is incident upon sensor array 215, which would otherwise reduce the SNR of the fingerprint system.

In another embodiment, shown in FIG. 6E, entrance edge 604 operates with optical power to optimize illumination of the location of the hologram of HOE 410. In FIG. 6E, entrance edge 604 as shown includes optical element 660. In this embodiment, lens element 602 (see FIGs. 6A-6D) can be eliminated. By way of example, optical power of entrance edge 604 can be designed to provide optimal

locations of dedicated areas of sensor array 215 are selected), by way of example, so as to be located at positions along the z-axis to independently detect the intensity of light diffracted by holograms 702 and 704, respectively. Sensors 720 and 722 can be located to detect the intensity of light diffracted by holograms 702 and 704 or instead to detect the intensity of the diffracted light from said holograms after the diffracted light has reflected at top surface 726 of skin contact layer 807. Preferably, although not a requirement, α_L, α_{HOE} and α_R are adjusted so that the intensities of light beam diffracted by hologram 702 and 704 and detected by the respective dedicated sensors are substantially equal at the values of incident angles for the Bragg matching condition of the respective holograms (shown as equal height peak in FIG. 7B). As can be seen from FIG. 7B, $\alpha_L < \alpha_{HOE} < \alpha_R$. As the result, as shown in FIG. 7C, when the angle for the Bragg matching condition of HOE 410 and holograms 702 and 704 changes due to temperature changing from T_1 to T_2, the dedicated sensors 720 and 722 will detect intensity of light beams diffracted from holograms 702 and 704 that are different from the respective intensities detected at temperature T_1 for the same angle of incidence α. The difference in intensity can be used to compute the control signals 393 or 396 or 398 or combinations thereof. It should be understood that logic 330 is designed to receive signals from the dedicated areas for processing differences in intensities.

An alternative embodiment comprises use of multiplexed holograms recorded in the photopolymer media of the HOE. The multiplexed holograms are recorded so that the Bragg selectivity's of these holograms are substantially overlapping. Use of multiplexed holograms that are recorded co-locationally can significantly reduce the sensitivity of the apparatus of this invention to temperature changes, or alignment changes, or wavelength changes, or combinations thereof. The multiplexed holograms, by way of example, can be multiplexed by the method of planar-angle multiplexing in a manner such that the increment of the recording angle is less than the width of the Bragg selectivity of each multiplexed hologram. Alternatively, these holograms can be multiplexed by varying the interbeam angle or the wavelength such that the grating period of each multiplexed hologram is slightly different so that the angular or wavelength selectivity characteristics of one such

camera microprocessor 335 in order to determine the correct operating wavelength to drive the wavelength controller 240.

In other embodiments, rather than changing the wavelength, a light source that has a broader wavelength spectrum can be used to reduce the sensitivity of the Bragg angle of the HOE to temperature change. Such light sources may include, for example, an LED or superluminescent LED. In these embodiments the incident angle α is held constant. As long as changes of the Bragg wavelength, produced by temperature changes of the HOE, are within the spectral bandwidth of the light source there will be a sufficient intensity of diffracted light to produce good imaging.

Other embodiments of the apparatus of this invention relate to physical construction of the device and will be described with reference to FIG. 6A. In one embodiment, entrance edge 604 of waveguide 405 forms an oblique angle to the top and bottom surfaces 610 and 612, said surfaces 610 and 612 being substantially parallel and planar surfaces. Use of an oblique angle for the entrance face of the waveguide advantageously reduces the thickness requirement for said slab waveguide. For example, with use of oblique angle for the entrance face, light beam 630 can be refracted directly towards top surface of waveguide 610 rather than towards bottom surface of waveguide 612 as it does in FIG. 6D. Refracting incident light 630 directly towards top surface, thereby eliminating the total internal reflection condition that is otherwise required for bottom surface of waveguide 612, reduces the z-dimension of waveguide 405. Alternatively, waveguide 405 can comprise inner and outer surfaces that may be curved so that a large topological surface of the skin can be placed on the outer surface at one time and imaged, such as could be the case when imaging the topological features of the surface of a palm. Again, use of an oblique angle for the entrance facet of the waveguide advantageously reduces the thickness requirement for said waveguide.

Other embodiments of the apparatus and method of this invention relate to the hologram recorded in the photopolymerizable media of the HOE. Referring to FIG. 8A, the apparatus of this invention preferably comprises HOE 410 that diffracts light (beam 826) in a direction that is not perpendicular to skin contact layer 807 so that the light reflected at the interface of skin contact layer 807 with air will not be

attached to skin contact layer 807, or it can be part of the cover plate, or it can be placed onto the cover plate before the fingerprint is captured. The pliable coating can be used to enhance image quality and reduce the dependence of SNR in the acquired fingerprint image on finger moisture or the wetting characteristic of the finger surface to skin contact layer 807 by improving the degree of optical contact between the surface topology of the skin of the finger and the skin contact layer.

In another embodiment skin contact layer 807 is formed from a material that has a refractive index that optimizes SNR of the captured image, such as fused silica, whereby the refractive index of the contact surface is similar to that of the surface of the finger or other skin surface.

Referring to FIG. 8D, the devices of the present invention can also include additional optical components. In one embodiment, the present invention includes wave plate 838, preferably ¼ waveplate, in combination with linear polarizer 840 to reduce detection of noise that can arise undesirably from sources such as diffuse and specular reflection. In this manner the contrast of the fingerprint image can be improved. In one configuration, ¼ wave plate 838 can be sandwiched between HOE 410 and skin contact layer 807 or 807A (see FIG. 8C), and the linear polarizer 840 is located between waveguide 405 and above sensor array 215. When linearly polarized light is diffracted from HOE 410 in a direction of ¼ wave plate 838, the polarization is transformed upon propagating through ¼ wave plate 838 to circularly polarized light. Upon reflection from either the top surface 726 of skin contact layer 807 or 807A or from ridge structure of the finger, the circularly polarized light is transformed by ¼ wave plate 838 back into linearly polarized light that has an electric field direction that is orthogonal to the original direction of the light entering HOE 410. When light, diffracted by HOE 410, interacts with the ridge structure of the finger surface that is in contact with the top surface 726 of skin contact layer 807 or 807A, both diffuse and specular reflections occur, with the former being stronger in some embodiments. When the diffracted light interacts with the top surface 726 of skin contact layer 807 or 807A at locations that correspond to a portion of skin surface that does not touch top surface 726 at these locations, only specular reflected light occurs. Detection of the noise contributions from the reflected light can substantially increase the level of grey-scale detected for portions of the captured

emitting diodes (LEDs) and/or semiconductor laser diodes. For reduced opto-mechanical alignment tolerances and simpler diffractive grating designs for HOE 410, it is desirable to collimate the radiation emitted from the light source. Lens element 602 is shown in FIG. 8A. Although a single transmissive lens is depicted, in general lens element 602 is composed of any combination of one or more transmissive and/or reflective optical elements such that the net optical effect is a substantial collimation of radiation emitted by light source 205. The collimated light emerging from lens element 602 is incident upon entrance edge 604 of waveguide 405. The angle φ_{SB} of the entrance edge 604 is specified so that optical axis 804 of the incident light beam propagating at an angle θ_1 (relative to the z-axis) is refracted at entrance edge 604 so that beam 822 propagates at an angle θ_{SB} with respect to the normal to the interface between waveguide 405 and HOE 410. As a result, a sufficiently large footprint of light illuminates HOE 410 and therefore illuminates finger 105 or other topological surface of the skin.

Referring to FIG. 8A, thickness T is defined as the distance that separates the top 726 of skin contact layer 807 to surface 814 of sensor array 215. For compactness of the device and in order to reduce the thickness T, which plays a role in defining the spatial resolution of the fingerprint sensor, it is desirable that the angle θ_{SB} be large, for example greater than about 70° but it is preferable that θ_{SB} be less than about 80° for otherwise the device will exhibit large sensitivity to thermal changes. By way of example, for $\theta_{SB} = 79°$ and a substrate block of thickness $T_{SB} = 3.3$ mm approximately 17 mm [3.3·tan(79°)] length of the skin topology can be imaged in the z-direction. For the case of $\theta_{SB} = 79°$, then with $\theta_1 = 17.5°$, and the substrate block composed of a material of index 1.53, $\varphi_{SB} = 90.9°$. Note that by having light source platform 662 tilted below the horizon, the opto-electro-mechanical components of the fingerprint sensor are allowed to lie below skin contact layer 807, thereby allowing for the housing 818 to be flush with said cover slide top.

Continuing to refer to FIG. 8A, the light, incident upon waveguide 405/HOE 410 interface, is refracted into HOE 410. In one embodiment, holographic grating of HOE 410 is a volume grating. One skilled in the art can design and engineer a

In one embodiment, there are several films, 810, 811 and 812, disposed between waveguide 405 and detector cover 813. These films may be arranged in many different manners, but their purpose serves to suppress reflections of light, in addition to filtering out unwanted noise. In one embodiment, film 810 is a linear polarizer film. Polarizer 810 preferentially has a polarization orientation substantially parallel to the polarization of the incident light ray 822. As such, polarizing film 810 suppresses portions of diffracted beam 826 that are scattered by finger 105 (and hence depolarized) from reaching sensor array 215. Film 811 is a wavelength filter. Wavelength filter 811 is preferentially tuned so that it substantially transmits wavelengths of light emitted by light source 205, and blocks all other wavelengths, and as such rejects ambient light originating outside of the housing 818 that would otherwise be incident upon sensor array 215. Film 811, by way of example, can be a dichroic film coating or a material that absorbs the desired spectral distribution of the ambient light, such as can be the case for a dyed plastic. Note that the wavelength filtering properties of film 811 can be incorporated into the bulk material or as a coating on either waveguide 405, skin contact layer 807, and/or detector cover 813, thereby eliminating the need for wavelength filter 811. Film 812 is an index-matching material where the index of refraction of said material preferentially matches within about 0.15 to the index of refraction of film 811 and detector cover 813. As a result, the intensity of reflected light at the interfaces of film 812 is not greater than about 0.25% of the intensity of the incident light at the boundaries of film 812. Alternatively, if index-matching material is not desired, it is preferred that the space shown occupied by film 812 be replaced by a small air gap (for example, approximately 0.1 to 0.2 mm) and that the film 811 and detector cover 813 each have an anti-reflection (AR) coating on their two opposing surfaces.

The light transmitted by detector cover 813 is incident upon sensor array 215. In one embodiment, sensor array 215 comprises a plurality of detector elements that enable a 2-D image of the fingerprint to be captured. Sensor array 215 can be a 2-D or 1-D charge coupled device (CCD), but is preferentially a detector requiring lower electrical power such as a 2-D or 1-D CMOS device. For the reduction of stray light, which for a coherent light source can lead to the creation of interference fringes that may be mistakenly construed for features on the skin being

skin contact layer 807 and the skin, but is minimized for the interface between skin contact layer 807 and air.

FIG. 8B depicts a top-down view of the embodiment of the device shown in FIG. 8A. In one embodiment, the width of the beam in the x-direction illuminating waveguide 405 and hence the illuminated width of finger 105 is dictated by the width of the beam that enters lens element 602. For the embodiment of light source 205 containing at least one semiconductor laser, the divergence of a semiconductor laser diode is anamorphic. With such an anamorphic beam, the angle of rays 823 (see FIG. 8A) and 824, emerging from light source 205 and representing the 50% drop in intensity level of the beam, will make angles of θ_s and θ_f, respectively, with respect to optical axis 804. For typical laser diodes, the ratio of these two angles is approximately 3:1, which means the beam is substantially elliptical in a cross section perpendicular to optical axis 804.

By way of example, consider the specification that the fingerprint device must be capable of examining a 17 x 17 mm area of skin. As illustrated earlier, a thickness T_{SB} of 3.3 mm can accommodate the 17 mm skin size in the z-direction. To accommodate the 17 mm in the x-direction, the waveguide must be at least 17 mm wide in this direction (as does the beam width of light in the x-direction from light source 205 that illuminates entrance edge 604). Therefore entrance edge 604 is substantially rectangular having dimensions in x and y of 17 mm and 3.3 mm, respectively. For maximum light efficiency, it is preferable that the fast axis of the laser (e.g., the axis of the laser that diverges the fastest), with full width at half maximum (FWHM) of $2\theta_f$, be in the direction of the 17mm width of waveguide 405 (corresponding to the x-axis). Likewise, the slow-axis (axis of the laser that diverges the slowest) having FWHM of $2\theta_s$, will correspond to the direction of the 3 mm thickness of waveguide 405.

In addition to the mechanical matching of beam widths and footprints for the area to be imaged of the topological surface of the skin, use of a diffraction optical element 410, that operates to diffract light so as to illuminate said surface of the skin, is generally polarization dependent. Consequently, use of correct polarization is preferred to achieve good SNR of the system. For a single transverse mode laser

Patent Application US 2003/0007201, the teachings of which are herein incorporated by reference in their entirety. Briefly, the diffraction efficiency of a hologram is a periodic function of the value of the grating strength of the hologram, which is dependent upon a material property, namely the value of its refractive index modulation. For photopolymer recording materials, the refractive index modulation, in turn, depends primarily on the degree of chemical segregation achieved in the recording material of the polymerizable component and the binder and the relative refractive index difference between the polymerizable component and the binder in the recording material, but it also may depend on thickness of the recording material, angles of incidence of the beams used to record the hologram and thereby the grating period, as well as the wavelength of the light used to record the hologram. For a given refractive index modulation achieved by the recording material, the grating strength is dependent upon similar parameters such as grating period, thickness, and wavelength. A hologram is optimized for a particular polarization when it is recorded using such combination of the above parameters that the resulting value of refractive index modulation corresponds to a peak of the diffraction efficiency. Ordinarily, the peaks of diffraction efficiencies of the holograms optimized for s- and p-polarized light do not occur at the same values of the refraction index modulation or grating strength (i.e. same values of the above-mentioned parameters). However, using the periodicity of the diffraction efficiency as a function of the value of the refractive index modulation or grating strength, it is possible to record a hologram that is optimized for both s- and p-polarized light. Since any light wave can be described as superposition of s- and p-polarized waves, a hologram that is simultaneously optimized for s- and p-polarized light is said to be polarization independent.

In the preferred embodiment of the device of the present invention, beam blocks 816 and 817 are integrated into the design. Beam block 816 is designed such that light from light source 205 does not enter sensor array 215 or any of the film layers, 810 through 812. Beam block 817 is designed so that light from light source 205 does not impinge onto finger 105, HOE 410, or skin contact layer 807. Both beam blocks 816 and 817 are positioned as close to entrance edge 604 as possible in order to minimize adverse diffraction effects due to the clipping of the light beam,

The grating geometry of FIG. 9 has the advantage that beam expansion in the *xz* plane is accomplished. The achieved beam expansion of the incident beam of diameter D_i is given by

$$\frac{D_r}{D_i} = \frac{\cos\theta_{-1}}{\cos\theta_i}, \tag{5}$$

where θ_{-1} is the angle of the diffracted -1st order reflected beam 901 measured relative to the grating surface normal 902 and θ_i is the angle of incidence of the incident beam 903 relative to grating surface normal 902.

As an example of such a reflective anamorphic beam expanding grating, consider a 1600 lp/mm reflection grating. Consider further that light source 205 is a semiconductor diode laser of 655 nm wavelength radiation and that beam 903 is incident upon said 1600 lp/mm reflection grating at $\theta_i = 85°$. The resultant diffracted negative first order propagates at $\theta_{-1} = 2.97$ and the expansion ratio D_r/D_i achieved is 11.5. Note that one skilled in the art can design and engineer other gratings (for example, surface-relief or volume), including gratings wherein the incident beam 903 transmits through a substrate such that it illuminates the grating from inside of the substrate material (for example a glass) which then transmits the required diffraction order for achieving the level of anamorphic beam expansion required. Whether a transmission or a reflection grating is designed to perform the required anamorphic beam expansion in the *xz* plane, it is preferable that the grating have a sufficiently high frequency such that a minimum number of diffraction orders propagate other than the order of interest. In this manner, one can make the distance between the grating 904 and the waveguide 405 as short as possible such that only a single diffraction order enters into the substrate block.

In the embodiment shown in FIG. 9, the diffracted beam 901 travels substantially parallel to the z-axis. The geometry of the fingerprint sensor illustrated in FIGs. 8A and 8B indicates the preference for a HOE 410 that has grating fringes that are primarily tilted in the *y-z* plane, but are approximately uniform along the *x*-direction. As such, HOE 410 has Bragg-matching conditions that require fractions of a degree of control of the light propagation angle in the *y-z* plane, but less stringent (>5 degrees) requirements for the angle of light propagation in the *x-z*

In 2003, 6.5 years later, said Polaroid photographic image was digitized by scanning at 600 dpi, and used as a training template for an example of the fingerprint correlation software of this invention. A new image of the same finger was acquired in 2003 using a fingerprint imager of this invention comprising the optical design of FIG. 4. The captured fingerprint was compared to the scanned image of the 6.5-year-old photograph of the original fingerprint. A positive identification, using locations of pores, the fine detail of the ridge contour at the boundaries of ridges and valleys, and minutiae was readily achieved, even though the said original and new images represent a finger area only 1/8" by 1/8", scale and rotation were different, the photograph had distortions due to being obtained from an image of the original fingerprint as displayed on a curved surface of a video monitor, and contrast and exposure were not matched nor calibrated in any way. At least 50 features, including 45 pores and 5 minutia points were captured from the original scan of the 1996 image, of which 22 pores and 5 minutia were present, detected and matched in the captured fingerprint imaged in 2003. The successful correlation results show that including pores in the fingerprint as well as the fine details of the ridge contour, by use of an apparatus that is capable of acquiring fingerprint images at high resolution, greatly increases the number of features that can be used for image correlation and significantly enhances the reliability of fingerprint comparison. Beneficial effects of the enhancements provided by the apparatus and method of this invention provide for reducing the occurrence of false acceptance, improving (through use of multiple templates) false reject rates, and significantly reducing the fingerprint sample area required for positive unique and deterministic authentication and identification.

FIG. 10 shows the Bragg detuning characteristics for 8 co-locationally multiplexed slant fringe plane-wave holograms recorded in 50 micron thick USLH-500-7A Aprilis holographic recording medium. Recording was carried out in the conventional manner using angle multiplexing where the increment of the recording angles for each of the co-locationally multiplexed holograms corresponds to twice the value for the full angle width at half height of the respective Bragg detuning curves. Each hologram was recorded with equal beam intensities of 4 mW in the Reference and Signal beam paths using spatially filtered and collimated light with a fixed value for the interbeam angle of 48.6°, and the sample was rotated about the

CLAIMS

1. An apparatus for fingerprint image acquisition comprising:

a waveguide, having an entrance edge and top and bottom surfaces;

a light source, configured to direct a light beam toward the entrance edge of the waveguide;

a skin contact layer, disposed at or near the top surface of the waveguide or bottom surface of the waveguide;

a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer;

a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer,

wherein the HOE includes

a layer comprising a grating; and

at least one supporting layer in contact with the said grating layer, wherein the grating layer and the at least one supporting layer have substantially similar coefficients of thermal expansion or thermo-optic coefficients or both.

2. An apparatus for image acquisition of topological features of the surface of skin comprising:

a waveguide, having an entrance edge and top and bottom surfaces;

a light source, configured to direct a light beam at the entrance edge of the waveguide;

a skin contact layer, disposed at or near the top surface or the bottom surface of the waveguide;

a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source to the skin contact layer;

a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer; and

wherein the means for compensating includes means for mounting one or more of the light source, the lens element or the waveguide, and

wherein the means for mounting is thermally expandable and is configured to adjust the angle of incidence of the light beam onto the waveguide or the HOE.

10. The apparatus of Claim 9 wherein the means for mounting one or more of the light source, the lens element or the waveguide comprises a rod or bar.

11. The apparatus of Claim 2 wherein the means for compensating includes one or more actuators, configured to adjust the angle of incidence of the light beam onto the waveguide or the HOE.

12. The apparatus of Claim 11 wherein further including an optional lens element.

13. The apparatus of Claim 12 wherein the actuator adjusts the position of one or more of the light source, the lens element or the waveguide.

14. The apparatus of Claim 12 wherein the position of one or more of the light source, the lens element or the waveguide is manually controlled by measuring intensity of the light diffracted by the HOE and detected by one or more of a plurality of pixels of the sensor array.

15. The apparatus of Claim 13 wherein the actuator is electronically controlled.

16. The apparatus of Claim 15 wherein intensity of the light reaching one or more of a plurality of pixels of the sensor array is measured to provide a signal that is used to control the actuator.

wherein the HOE includes at least two co-locationally multiplexed holograms.

22. The apparatus of Claim 21 wherein the multiplexed holograms are configured so that the Bragg matching condition of the multiplexed holograms is substantially overlapping.

23. The apparatus of Claim 21 wherein the multiplexed holograms are planar-angle multiplexed and wherein the increment of the recording angle for multiplexing is less than the width of the angle Bragg matching condition of each earlier-recorded multiplexed hologram.

24. The apparatus of Claim 21 wherein the grating periods of the multiplexed hologram are not equal.

25. An apparatus for image acquisition of topological features of the surface of skin comprising:

a waveguide, having an entrance edge and top and bottom surfaces;

a light source, configured to direct a light beam at the entrance edge of the waveguide;

a skin contact layer, disposed at the top or bottom surface of the waveguide;

a holographic optical element (HOE), disposed at the top or at the bottom surfaces of the waveguide, configured to diffract the light beam incident from the light source at the skin contact layer;

a sensor array, configured to detect light reflected from the interface between skin and the skin contact layer; and

means for changing the wavelength of the light source.

26. The apparatus of Claim 34 wherein the means for changing the wavelength of the light source is a laser diode configured to change the operating

wherein the light source is a broad wavelength spectrum light source, the wavelengths of which can reconstruct the HOE.

33. The apparatus of Claim 32 further including a lens element, configured to direct the light beam from the light source at the entrance edge of the waveguide.

34. The apparatus of Claim 32 wherein the HOE is configured to diffract the light beam in a direction that differs from the perpendicular to the skin contact layer by an angle

35. The apparatus of Claim 34 wherein the HOE has a diffraction efficiency of at least about 50%.

36. The apparatus of Claim 34 wherein the HOE has a diffraction efficiency of at least about 75%.

37. The apparatus of Claim 34 wherein the HOE has a diffraction efficiency of at least about 90%.

38. The apparatus of Claim 32 wherein the HOE includes at least two multiplexed holograms.

39. The apparatus of Claim 32 wherein the HOE is optimized for s-polarized incident beam.

40. The apparatus of Claim 32 wherein the HOE is optimized for p-polarized incident beam.

41. The apparatus of Claim 32 wherein the HOE is polarization independent.

52. The apparatus of Claim 32 wherein the skin contact layer has a refractive index that is between about 1.30 and about 1.50.

53. The apparatus of Claim 32 wherein the skin contact layer comprises a portion having optical power configured to direct the light reflected from the interface between skin and the skin contact layer to the sensor array.

54. The apparatus of Claim 53 wherein the portion having optical power is curved.

55. The apparatus of Claim 53 wherein the portion having optical power is a plano-convex lens.

56. The apparatus of Claim 32 further including an additional lens element attached to the skin contact layer configured to direct the light reflected from the interface between skin and the skin contact layer to the sensor array.

57. The apparatus of Claim 32 wherein the skin contact layer comprises layer of a polymer having a glass transition temperature less than ambient use temperature of the device.

58. The apparatus of Claim 32 wherein the skin contact layer is coated with a layer of polymer having a glass transition temperature less than ambient use temperature of the device.

59. The apparatus of Claim 32 wherein the skin contact layer comprises a glass material having refractive index between about 1.45 and 1.50.

60. The apparatus of Claim 32 wherein the skin contact layer comprises a top surface having surface energy of less than about 30 mJ/m^2.

70. The apparatus of Claim 69 wherein the dielectric layer includes derivatives of silicone or siloxane.

71. The apparatus of Claim 32 wherein the sensor array has a resolution of at least 1100 pixels per inch in the acquired image.

72. The apparatus of Claim 32 wherein the sensor array is a CCD or CMOS imagers.

73. A method of acquiring an image of the topology of the surface of skin, comprising:

receiving a surface of skin by a device for image acquisition of the topological features of the surface of skin wherein said device includes a holographic optical element (HOE) having a Bragg matching condition;

directing a light beam at the HOE, thereby diffracting the light beam;

directing the diffracted light beam at the interface between skin and the skin contact layer, thereby reflecting the light beam;

compensating for temperature-induced changes in the Bragg matching condition of the HOE; and

detecting the reflected light, thereby acquiring the image of the topological features of the surface of skin by said device.

74. The method of Claim 73 wherein compensating for temperature-induced changes in the Bragg matching condition of the HOE includes controlling the temperature of the HOE.

75. The method of Claim 73 wherein the HOE includes a diffraction grating having at least one dimension that is greater than the cross-section of the light beam, and

wherein the light beam is directed at the HOE at an angle that is less than about 90° with respect to the plane of the HOE, said HOE diffracting

mounting means to be thermally expandable and configuring the selected means to adjusts the angle of incidence of the light beam onto the HOE.

80. The method of Claim 79 wherein the means for mounting the light source is a thermally expandable rod or bar.

81. The method of Claim 79 wherein the image acquisition device further includes a controllable actuator, configured to adjust an angle of incidence of the light beam onto the HOE.

82. The method of Claim 76 wherein the position of one or more of the light source, the lens element or the waveguide is manually controlled by measuring the intensity of the light diffracted by the HOE and detected by one or more of a plurality of pixels of the sensor array.

83. The method of Claim 76 wherein the device further includes at least one additional sensor, and

further wherein the position of one or more of the light source, the lens element or the waveguide is manually controlled by measuring the intensity of the light diffracted by the HOE and detected by the at least one additional sensor.

84. The method of Claim 81 wherein compensating for the temperature-induced changes in the Bragg matching condition of the HOE includes controlling the actuator by an electrical signal.

85. The method of Claim 84 wherein the device further includes at least one additional sensor, and

wherein controlling the actuator includes measuring intensity of the light reaching the sensor array or at least additional sensor, thereby providing the electrical signal.

92. The method of Claim 78 wherein the light source is a laser diode, and wherein compensating for temperature-induced changes in the Bragg matching condition of the HOE includes configuring the laser diode to change the operating wavelength in response to temperature.

93. The method of Claim 76 wherein compensating for temperature-induced changes in the Bragg matching condition of the HOE includes configuring the light source to produce a broad wavelength spectrum light.

94. The method of Claim 76 further including selecting the HOE that diffracts the light beam in a direction that differs from the perpendicular to the skin contact layer by an angle that exceeds the angular width of the Bragg angle selectivity of the main hologram.

95. The method of Claim 76 further including selecting the HOE that includes at least two multiplexed holograms.

96. The method of Claim 94 further including selecting the HOE so that each of the multiplexed holograms has a diffraction efficiency of at least about 50%.

97. The method of Claim 94 further including selecting the HOE so that each of the multiplexed holograms has a diffraction efficiency of at least about 75%.

98. The method of Claim 94 further including selecting the HOE so that each of the multiplexed holograms has a diffraction efficiency of at least about 90%.

99. The method of Claim 73 further including selecting the HOE that is optimized for s-polarized light.

100. The method of Claim 73 further including selecting the HOE that is optimized for p-polarized light.

light reflected from the interface between skin and the contact layer at the sensor array.

110. The method of Claim 76 wherein the skin contact layer comprises layer of a polymer having a glass transition temperature less than ambient use temperature of the device.

111. The method of Claim 76 wherein the skin contact layer is coated with a layer of polymer having a glass transition temperature less than ambient use temperature of the device.

112. The method of Claim 76 wherein the skin contact layer comprises a glass material having refractive index between about 1.45 and 1.50.

113. The method of Claim 76 wherein the skin contact layer comprises a top surface having surface energy of less than about 30 mJ/m^2.

114. The method of Claim 76 further including at least one of a ¼ wave plate and a linear polarizer disposed between the skin contact layer and the sensor array.

115. The method of Claim 114 wherein the ¼ wave plate is disposed between the HOE and the skin contact layer and the linear polarizer is disposed between the waveguide and the sensor array.

116. The method of Claim 76 wherein the light source wavelength that is in a range from about 400 nm to about 1000 nm.

117. The method of Claim 116 wherein the light source wavelength is in a range from about 400 nm to about 535 nm.

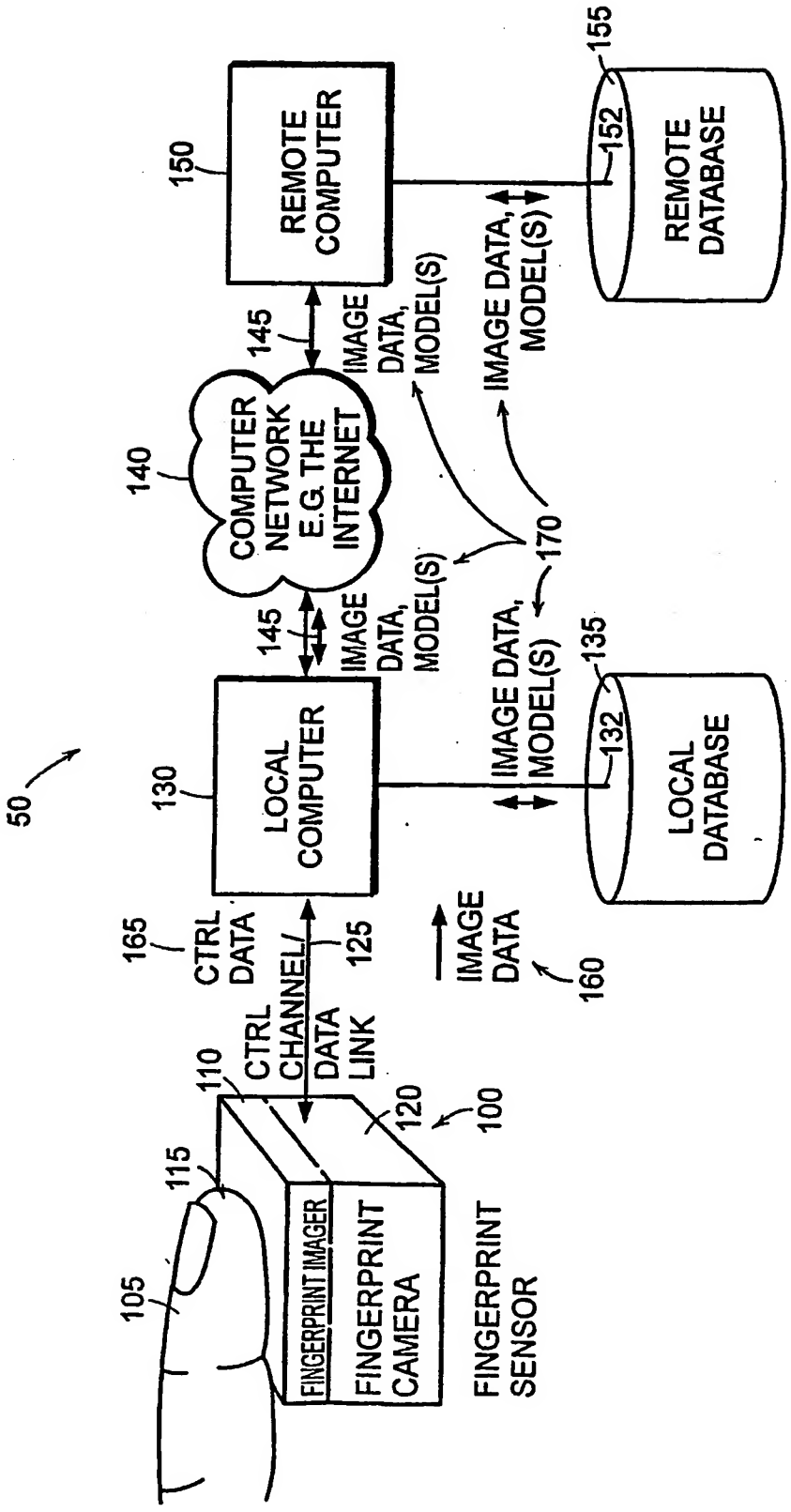

50
105
110
115
120
100
FINGERPRINT IMAGER
FINGERPRINT CAMERA
FINGERPRINT SENSOR
CTRL CHANNEL/ DATA LINK
125
165
CTRL DATA
IMAGE DATA
160
130
LOCAL COMPUTER
135
132
LOCAL DATABASE
IMAGE DATA, MODEL(S)
145
IMAGE DATA, MODEL(S)
170
140
COMPUTER NETWORK E.G. THE INTERNET
145
IMAGE DATA, MODEL(S)
150
REMOTE COMPUTER
155
152
REMOTE DATABASE
IMAGE DATA, MODEL(S)

FIG. 1

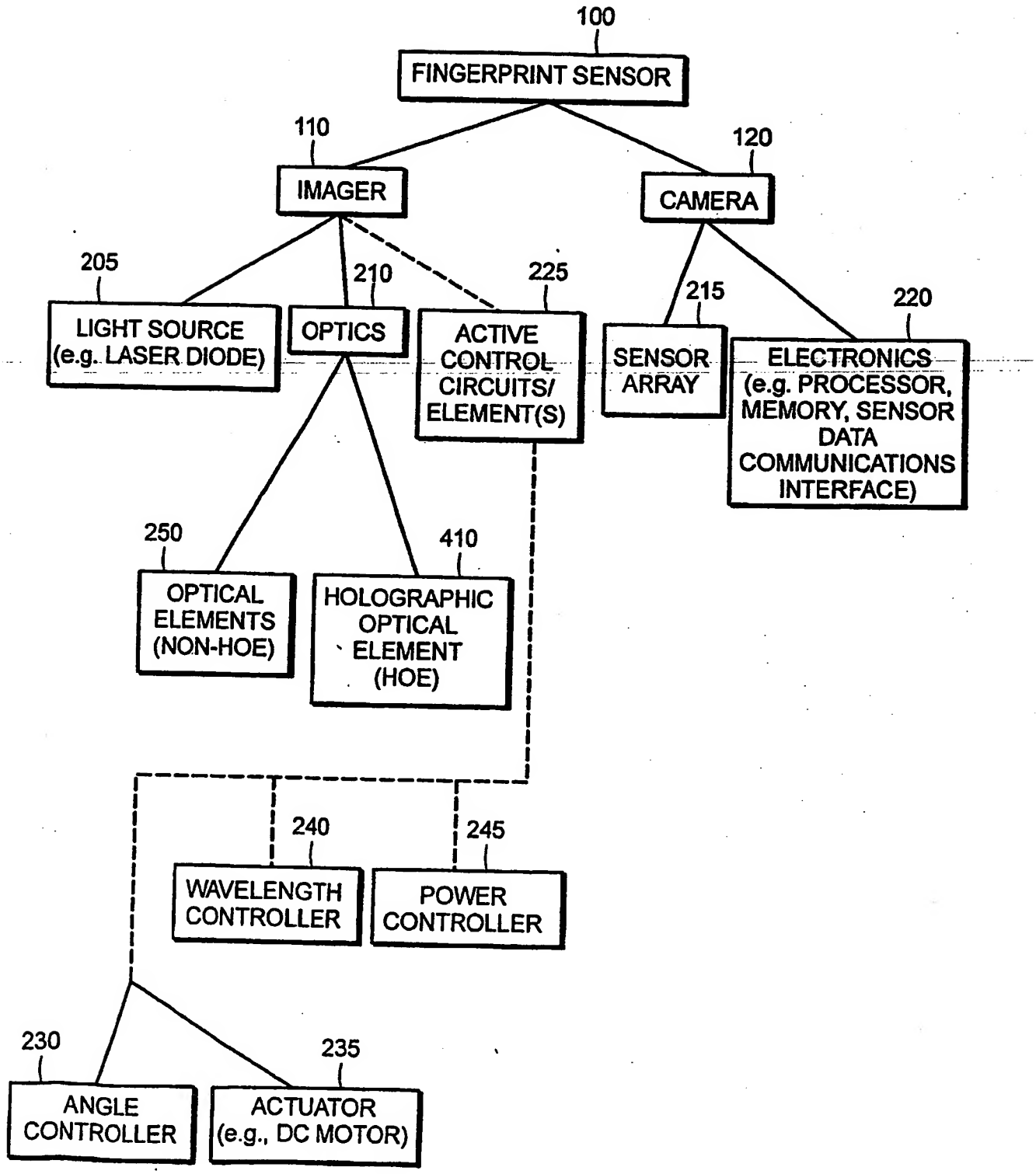

100
FINGERPRINT SENSOR
110
IMAGER
120
CAMERA
205
LIGHT SOURCE (e.g. LASER DIODE)
210
OPTICS
225
ACTIVE CONTROL CIRCUITS/ ELEMENT(S)
215
SENSOR ARRAY
220
ELECTRONICS (e.g. PROCESSOR, MEMORY, SENSOR DATA COMMUNICATIONS INTERFACE)
250
OPTICAL ELEMENTS (NON-HOE)
410
HOLOGRAPHIC OPTICAL ELEMENT (HOE)
240
WAVELENGTH CONTROLLER
245
POWER CONTROLLER
230
ANGLE CONTROLLER
235
ACTUATOR (e.g., DC MOTOR)

FIG. 2

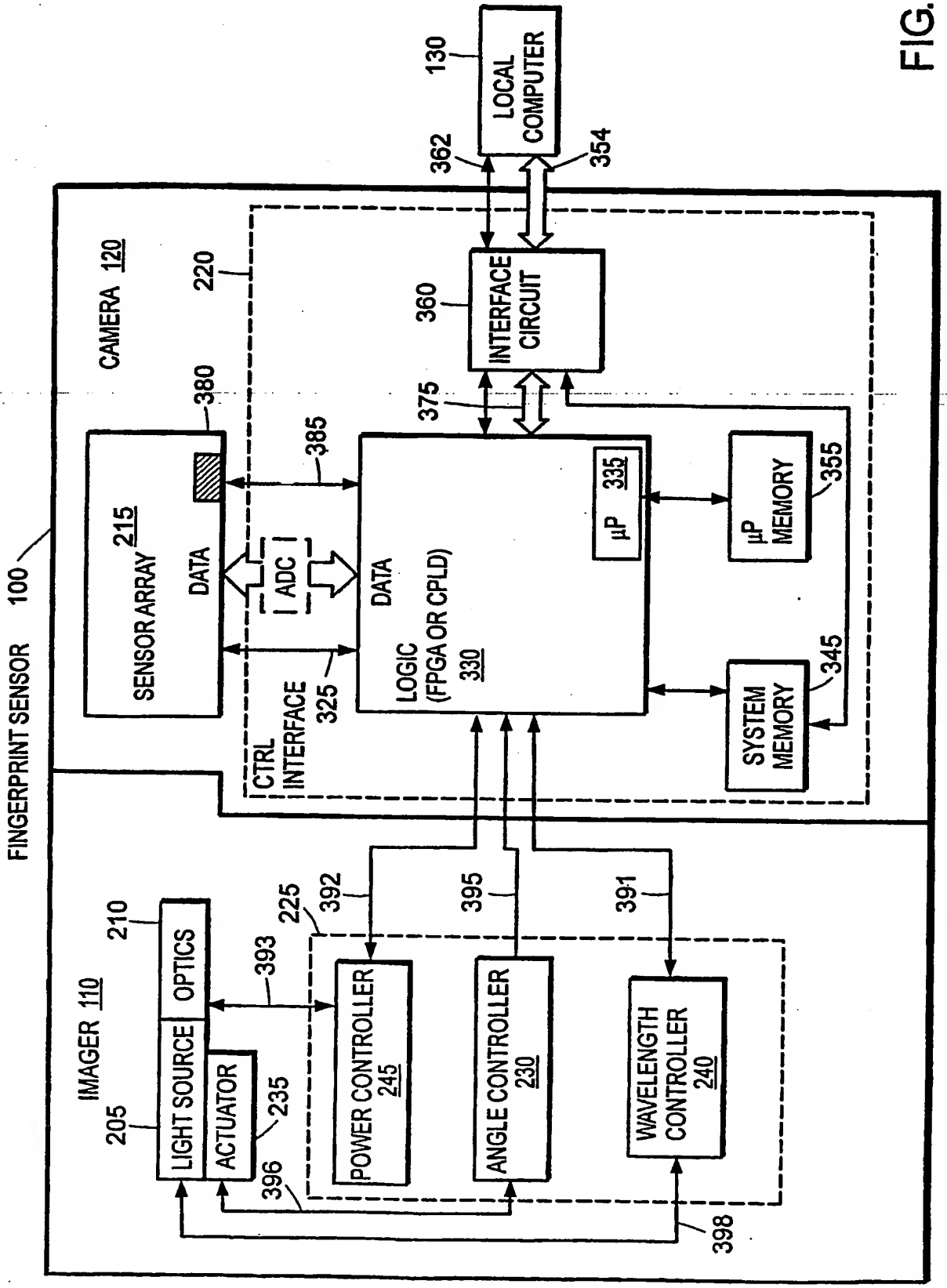

FINGERPRINT SENSOR 100
CAMERA 120
220
LOCAL COMPUTER
130
362
354
INTERFACE CIRCUIT
360
375
380
385
SENSOR ARRAY 215
DATA
ADC
DATA
LOGIC (FPGA OR CPLD) 330
μP 335
μP MEMORY
355
SYSTEM MEMORY
345
CTRL INTERFACE
325
IMAGER 110
210
OPTICS
LIGHT SOURCE
ACTUATOR
205
235
393
225
392
395
391
POWER CONTROLLER 245
ANGLE CONTROLLER 230
WAVELENGTH CONTROLLER 240
396
398

FIG. 3

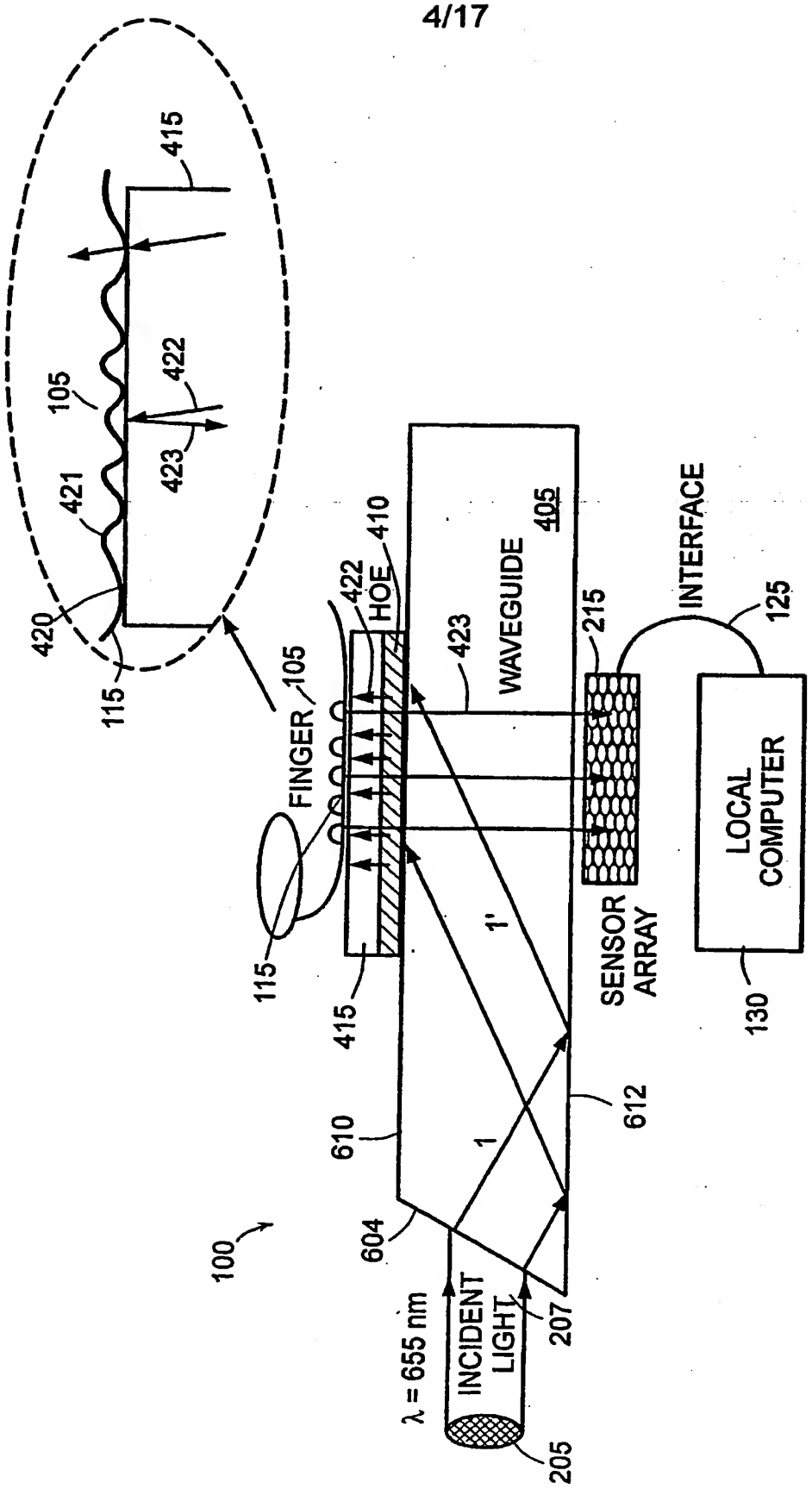

415
105
422
423
421
420
115
410
HOE
422
105
FINGER
423
WAVEGUIDE
405
215
INTERFACE
125
LOCAL COMPUTER
130
SENSOR ARRAY
115
415
1'
610
612
1
604
100
λ = 655 nm
INCIDENT LIGHT
207
205

FIG. 4

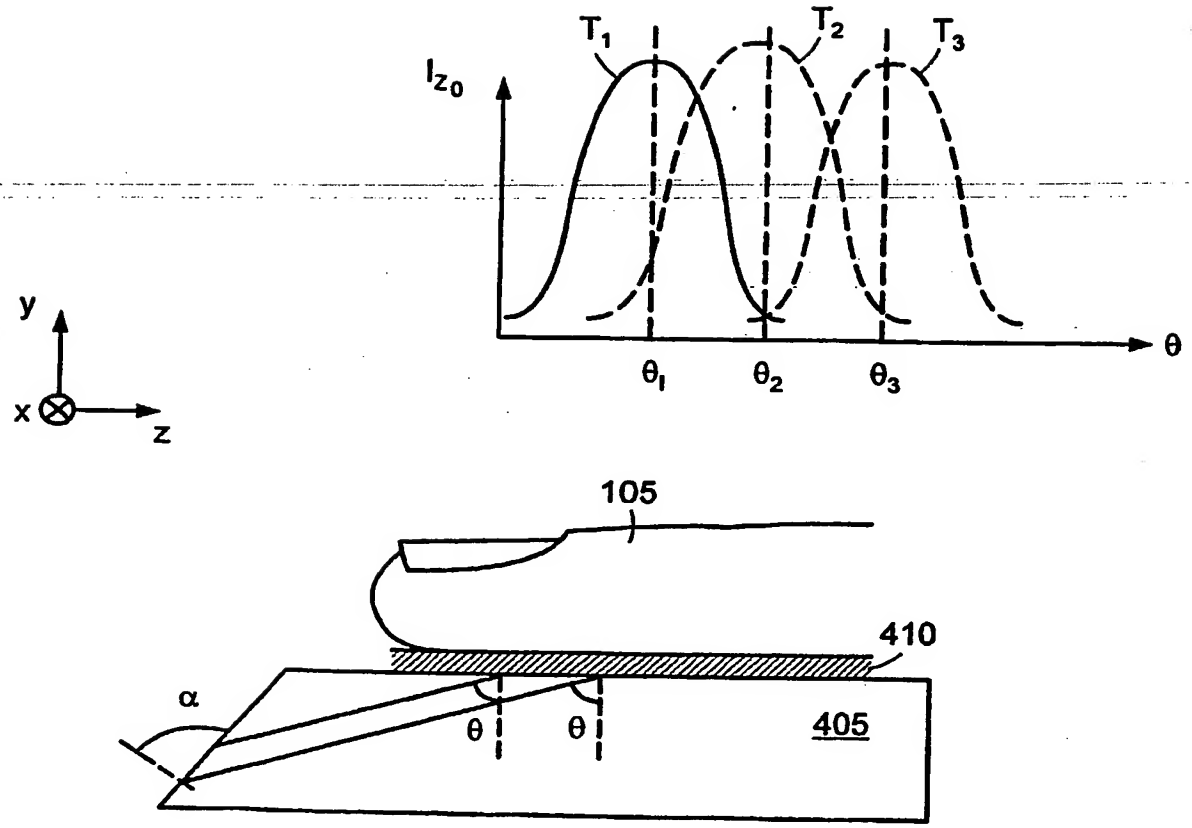


FIG. 5

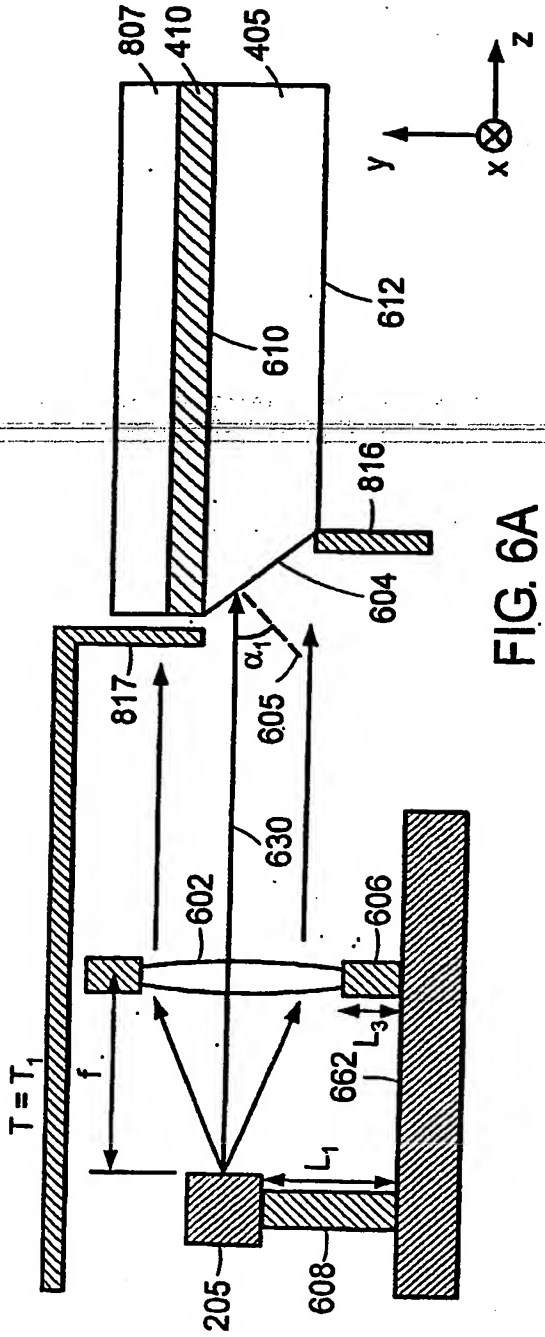

807
410
405
z
y
x
612
610
816
604
α_1
605
817
630
602
606
$T = T_1$
f
L_3
662
L_1
205
608

FIG. 6A

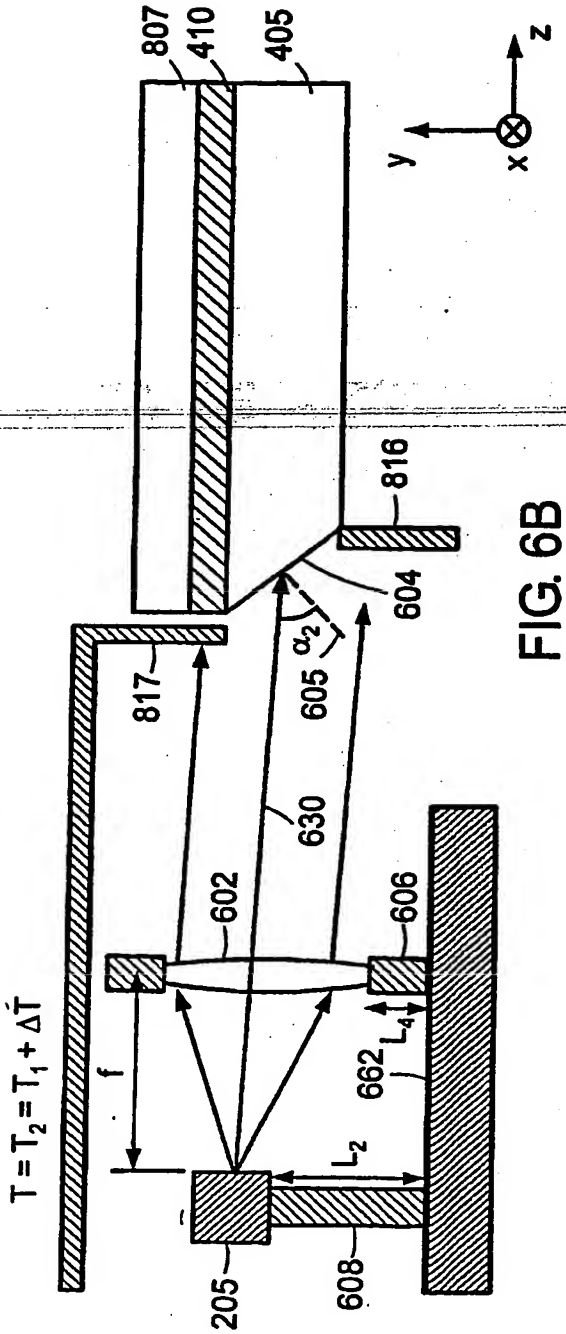

807
410
405
z
y
x
816
604
α_2
605
817
630
602
606
$T = T_2 = T_1 + \Delta T$
f
L_4
662
L_2
205
608

FIG. 6B

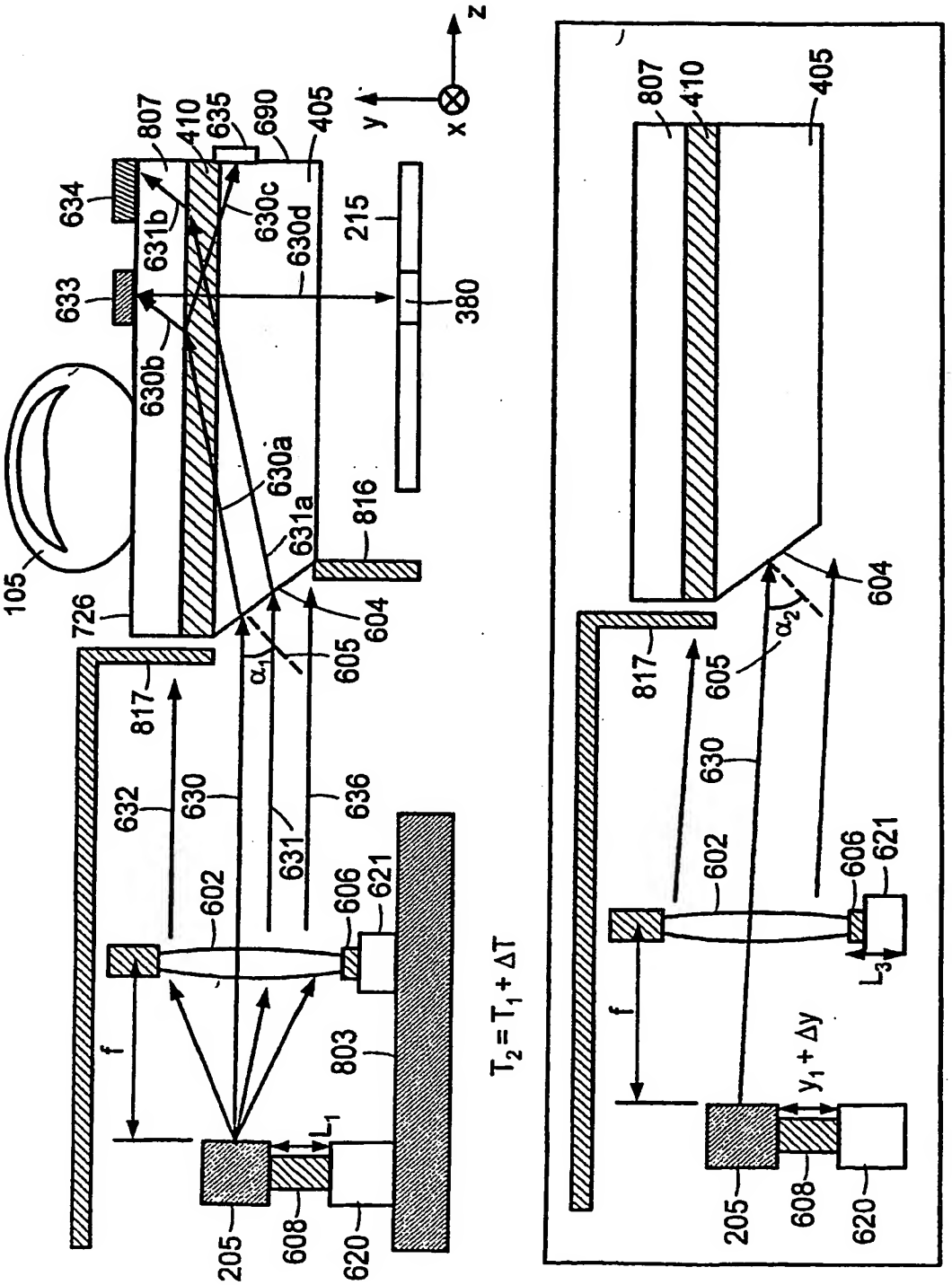

z
y
x
807
410
635
690
405
634
631b
630c
630d
215
633
380
630b
630a
631a
816
105
726
604
605
α_1
817
632
630
636
631
602
606
621
803
f
L_1
205
608
620
$T_2 = T_1 + \Delta T$
807
410
405
604
α_2
817
605
630
602
606
621
L_3
f
$y_1 + \Delta y$
205
608
620

FIG. 6C

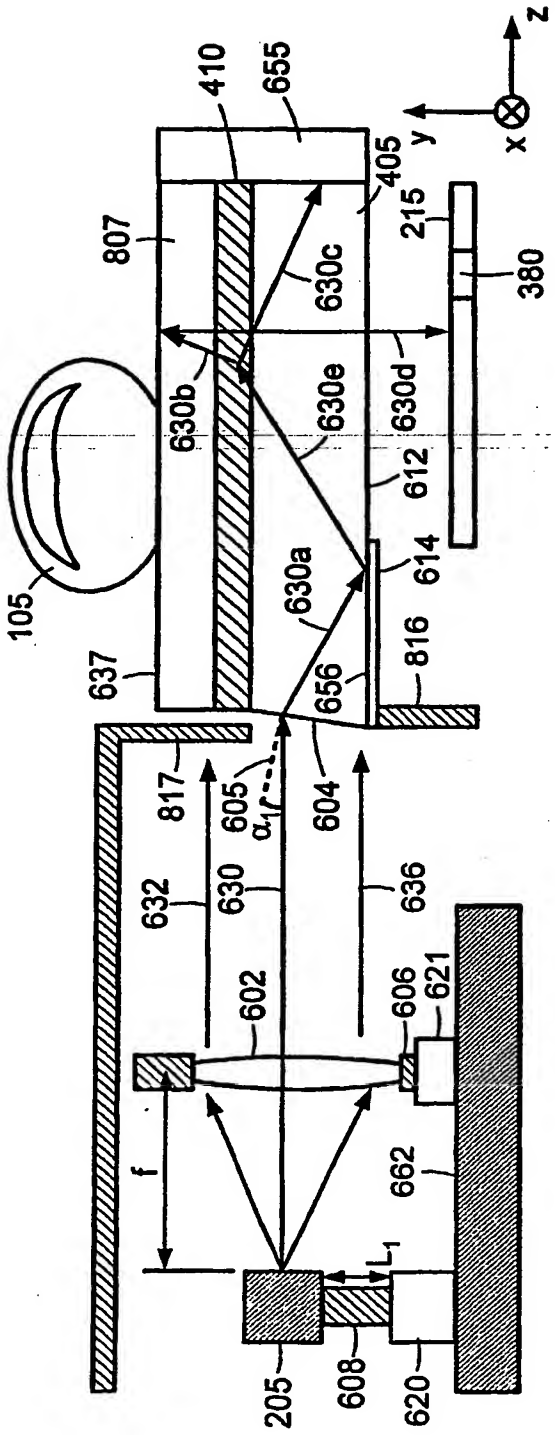

z
y
x
410
655
405
807
215
380
630c
630b
630e
630d
612
614
630a
105
637
816
656
604
605
α_1
817
632
630
636
602
606
621
662
f
L_1
205
608
620

FIG. 6D

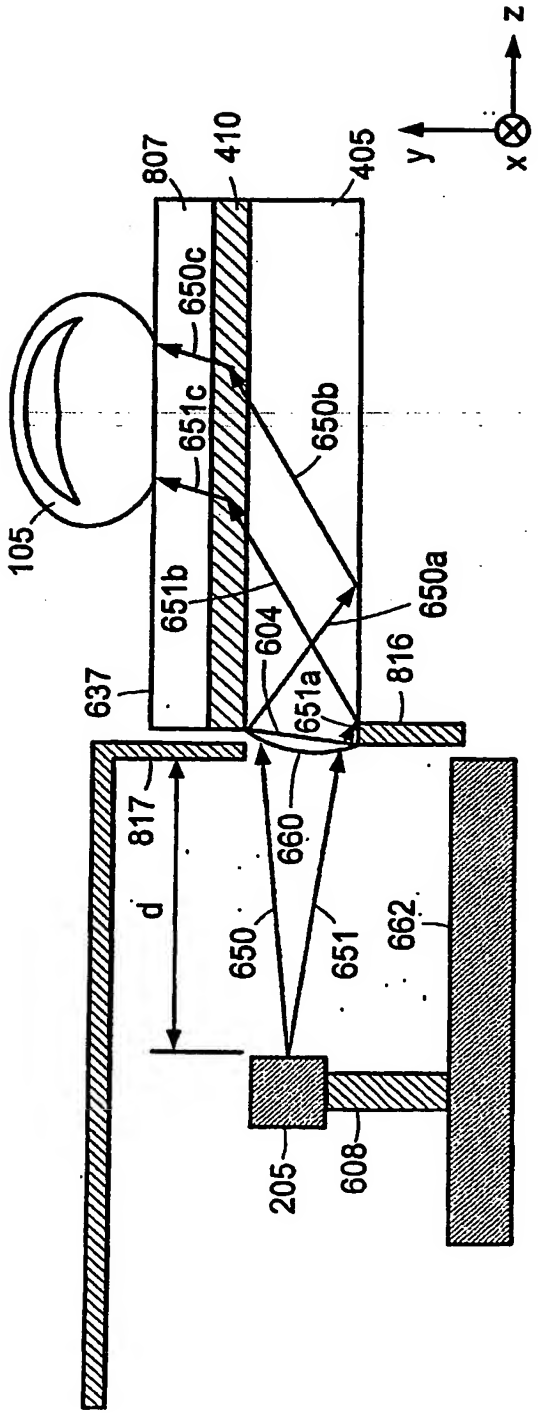

z
y
x
807
410
405
650c
651c
650b
105
651b
650a
604
816
637
651a
817
660
d
650
651
662
205
608

FIG. 6E

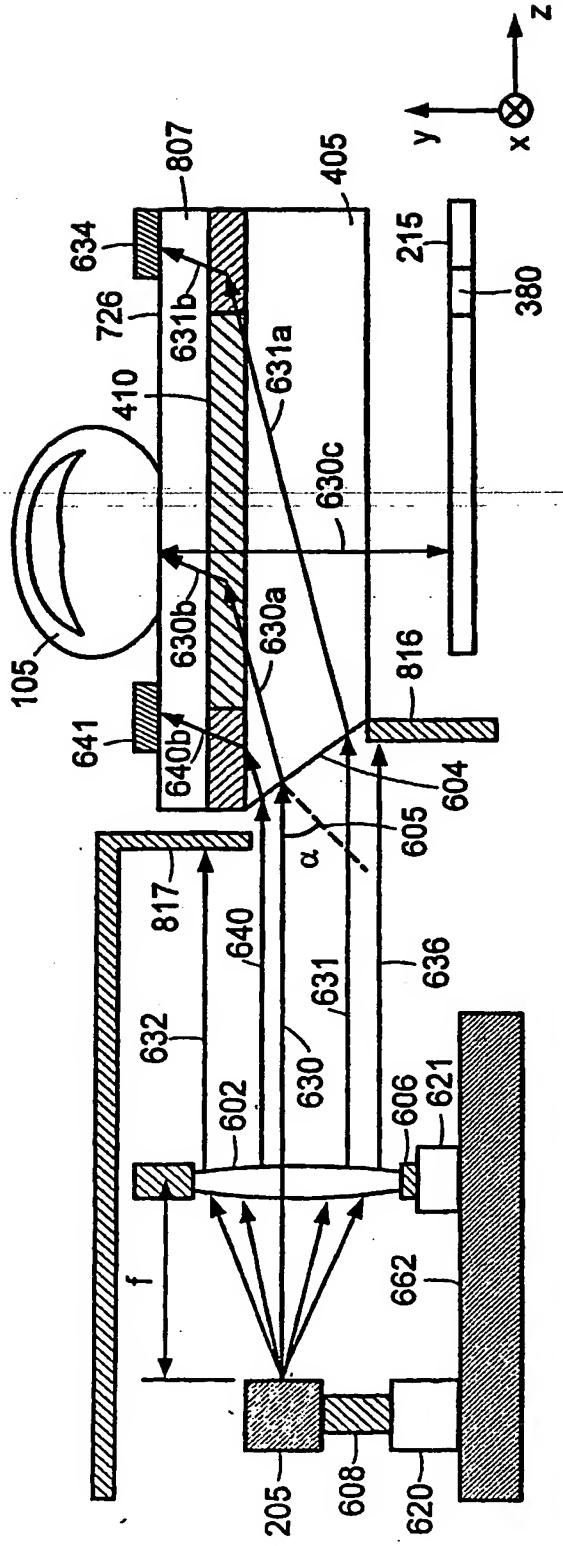

z
y
x
807
405
634
215
726
631b
631a
380
410
630c
630b
630a
816
105
641
640b
604
605
α
817
640
636
631
632
630
602
606
621
f
662
205
608
620

FIG. 7A

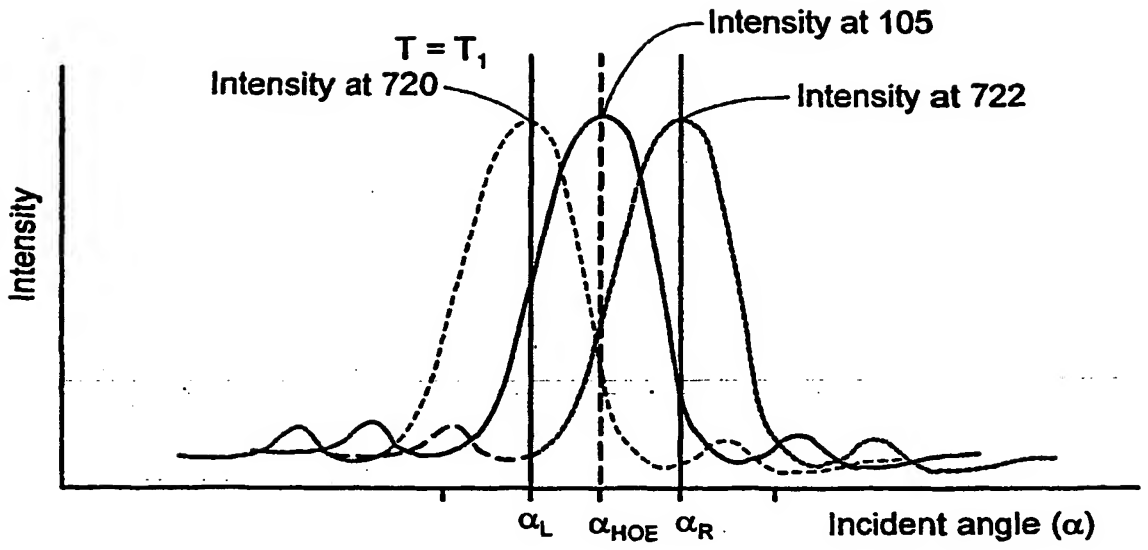

T = T1
Intensity at 720
Intensity at 105
Intensity at 722
Intensity
αL
αHOE
αR
Incident angle (α)

FIG. 7B

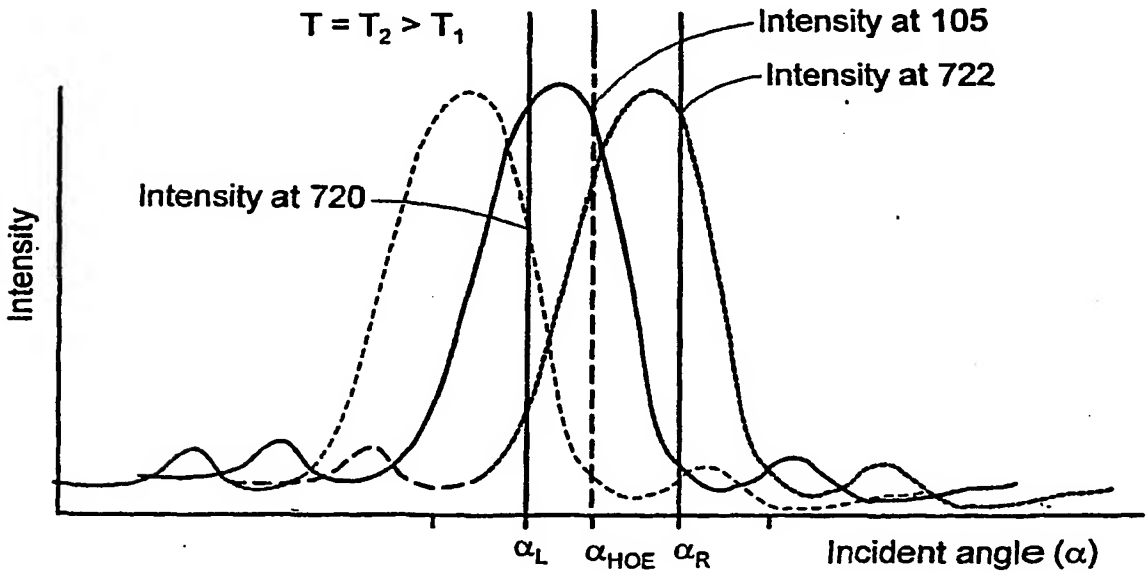

T = T2 > T1
Intensity at 105
Intensity at 722
Intensity at 720
Intensity
αL
αHOE
αR
Incident angle (α)

FIG. 7C

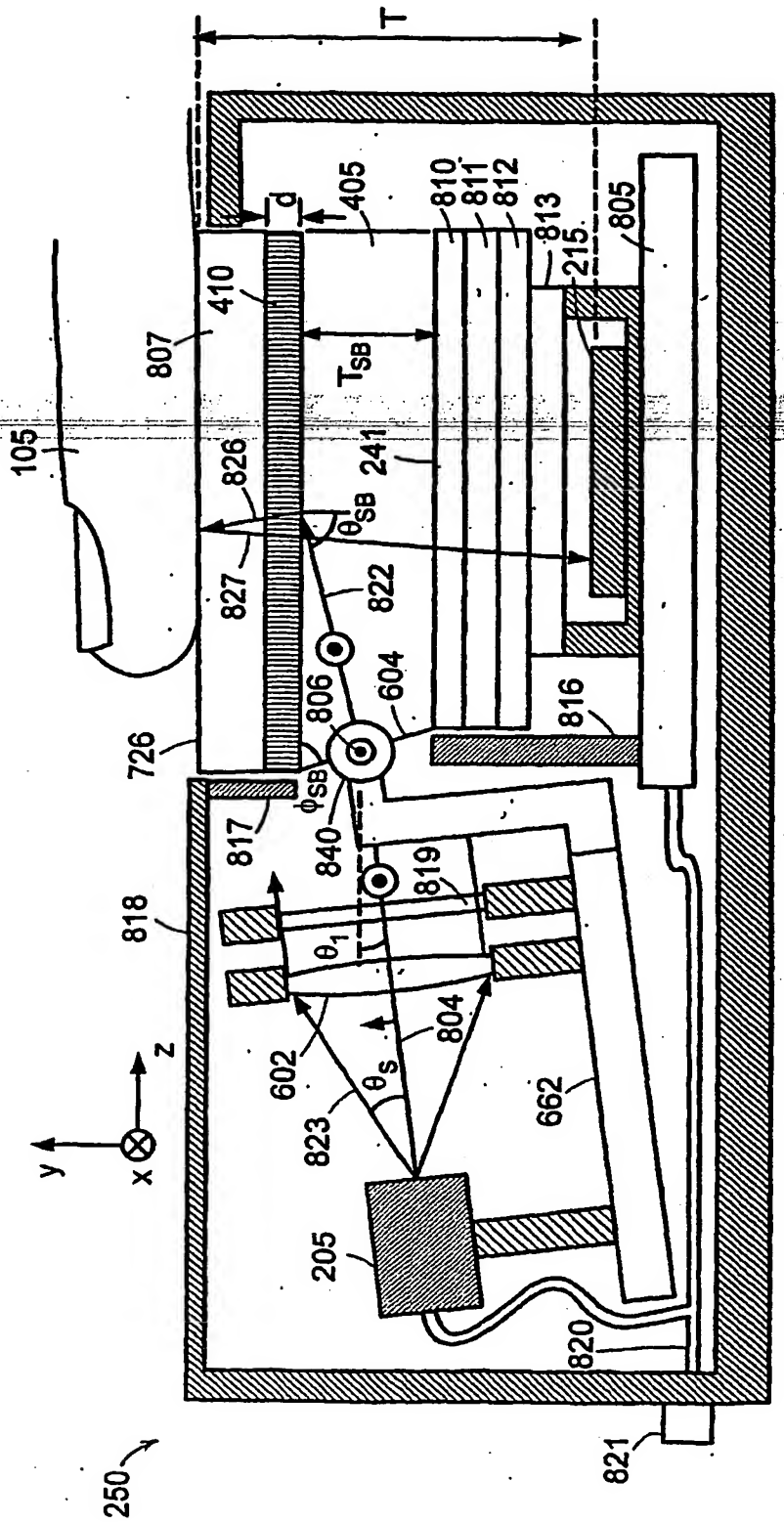

T
d
405
810
811
812
813
805
215
410
807
T_{SB}
105
826
241
θ_{SB}
827
822
604
806
816
726
ϕ_{SB}
817
840
819
818
θ_1
804
602
θ_s
662
823
205
820
821
250
z
y
x

FIG. 8A

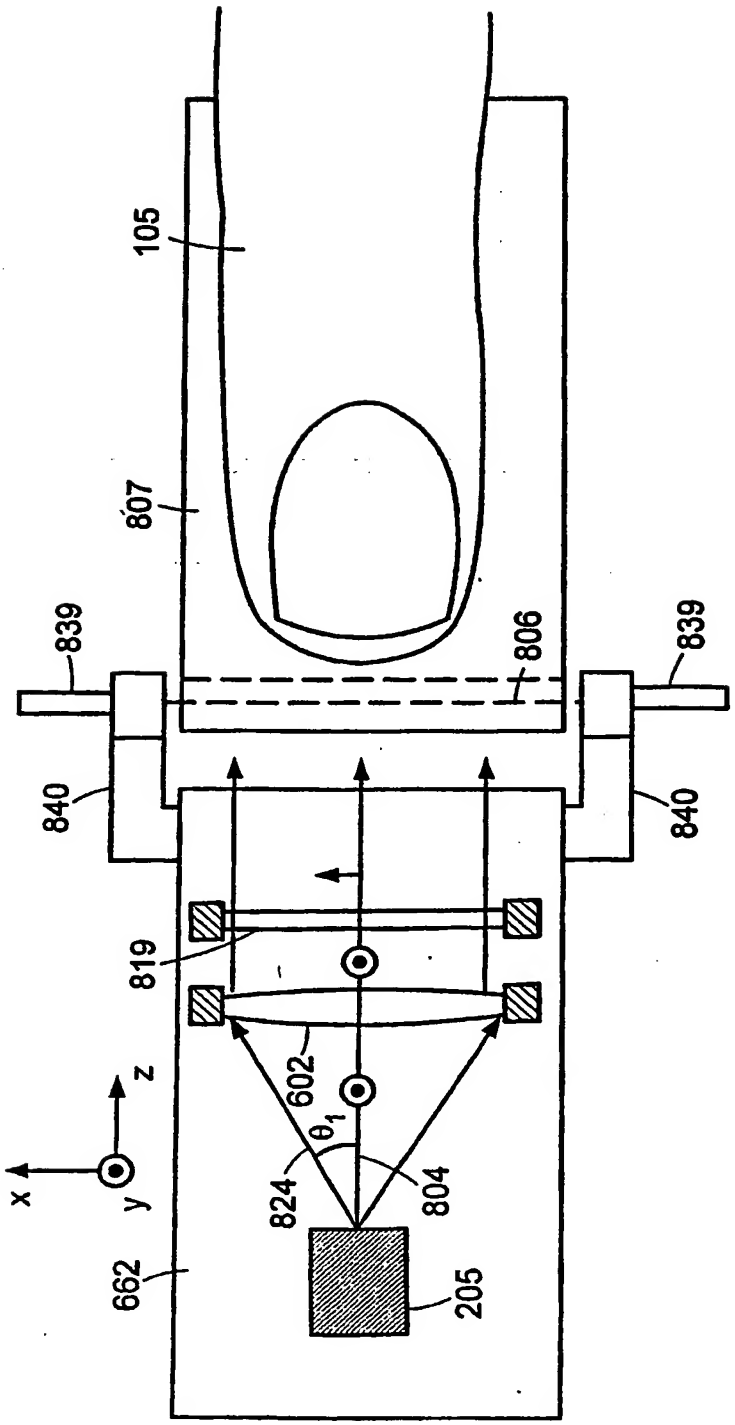


FIG. 8B

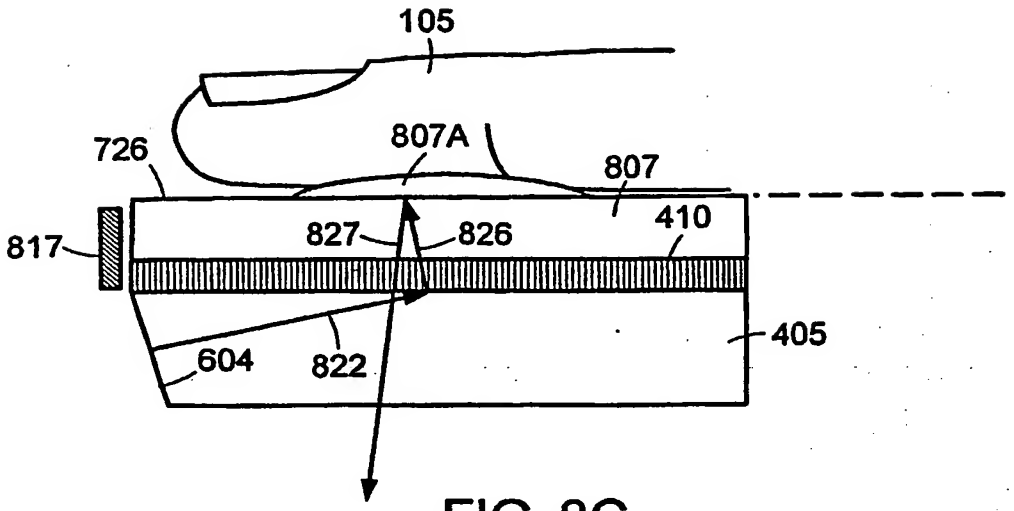

105
726
807A
807
817
827
826
410
405
604
822

FIG. 8C

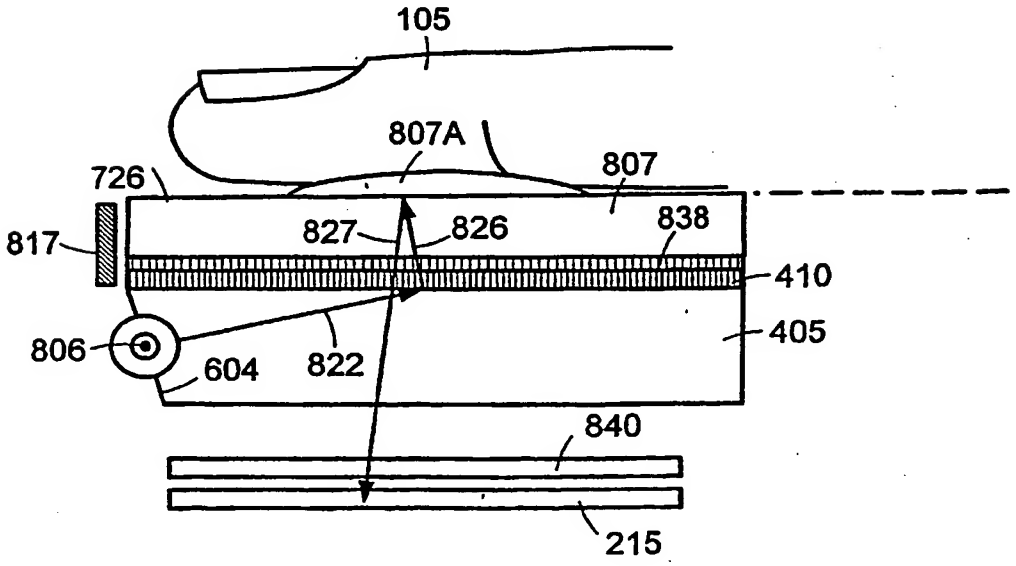

105
807A
726
807
817
827
826
838
410
405
806
604
822
840
215

FIG. 8D

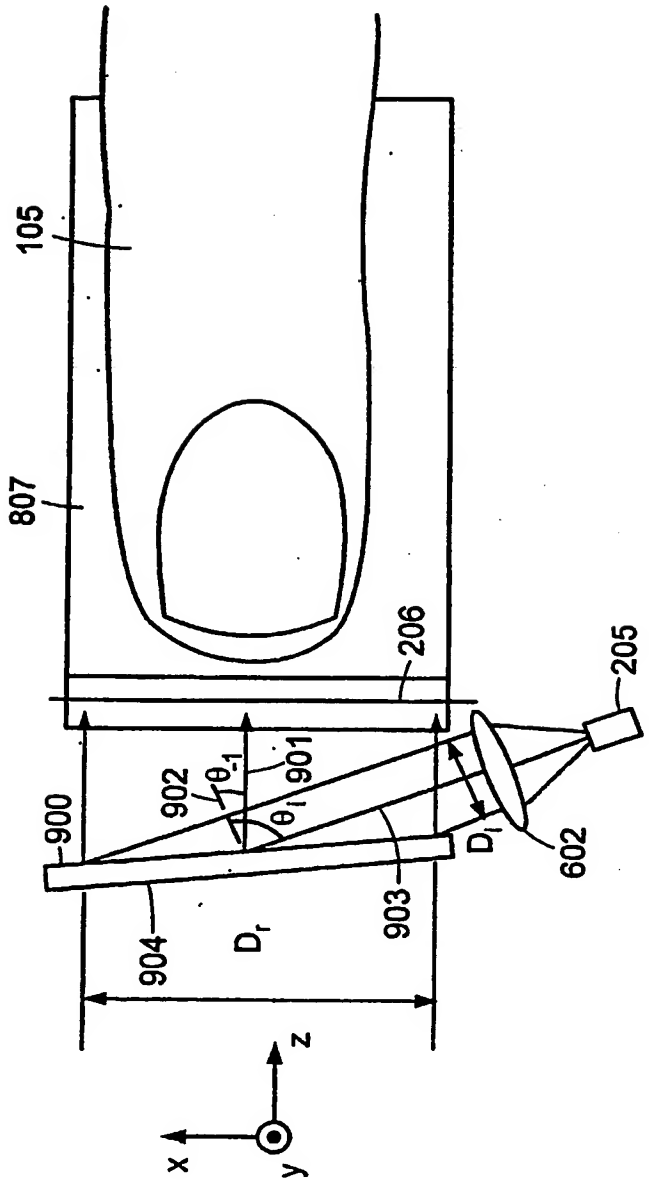


FIG. 9

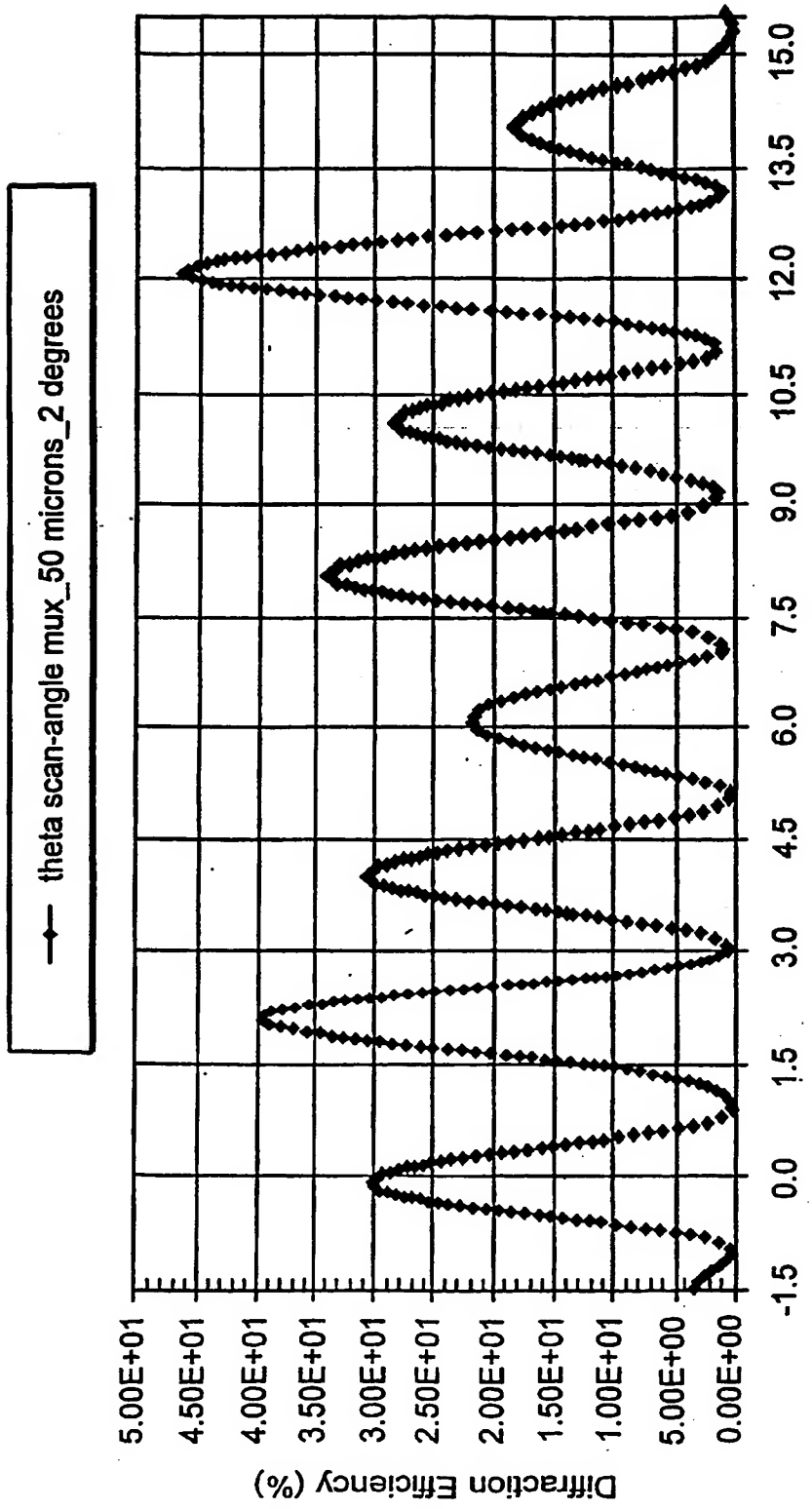

theta scan-angle mux_50 microns_2 degrees
Diffraction Efficiency (%)
5.00E+01
4.50E+01
4.00E+01
3.50E+01
3.00E+01
2.50E+01
2.00E+01
1.50E+01
1.00E+01
5.00E+00
0.00E+00
-1.5
0.0
1.5
3.0
4.5
6.0
7.5
9.0
10.5
12.0
13.5
15.0
Theta (°)

FIG. 10

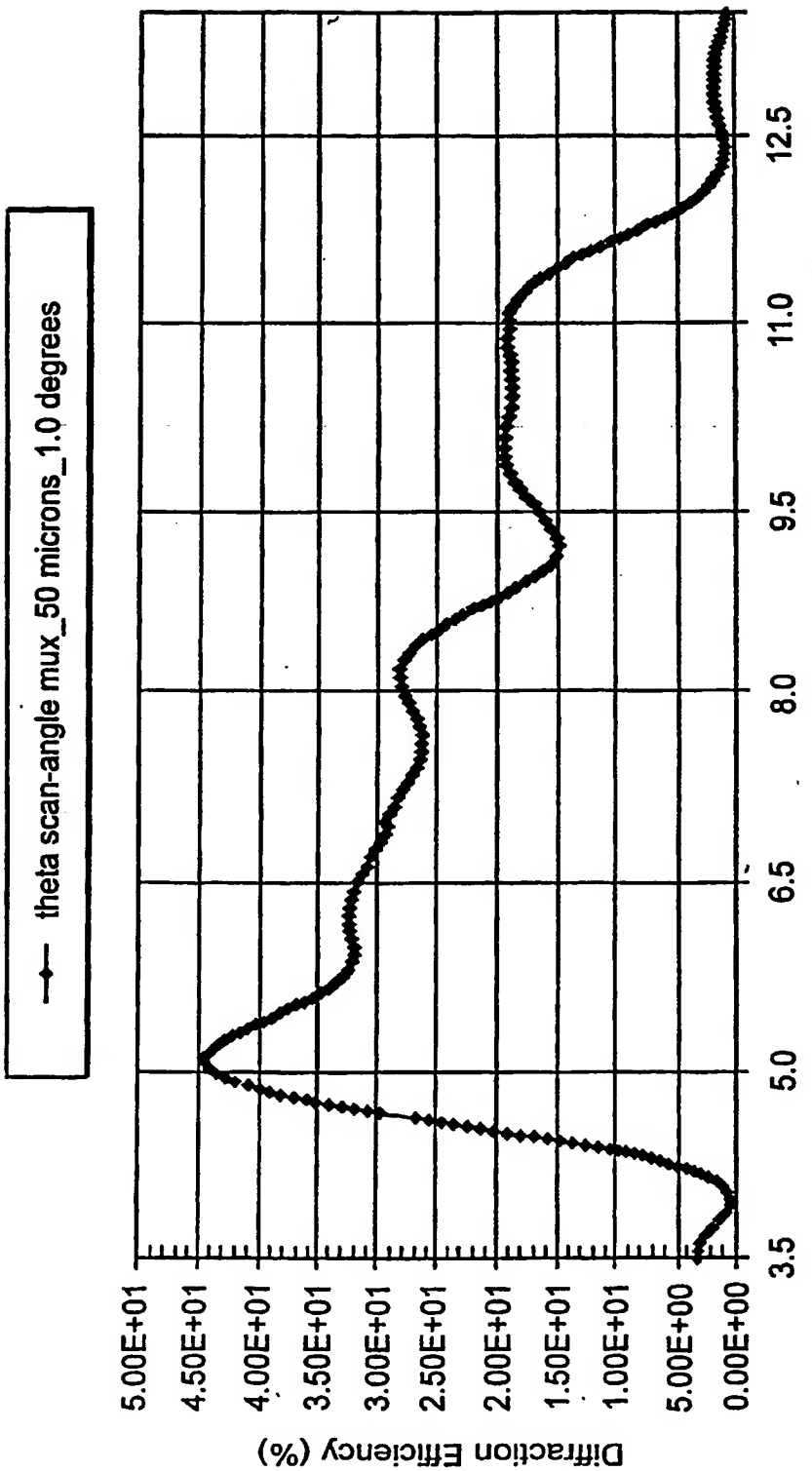

theta scan-angle mux_50 microns_1.0 degrees
Diffraction Efficiency (%)
5.00E+01
4.50E+01
4.00E+01
3.50E+01
3.00E+01
2.50E+01
2.00E+01
1.50E+01
1.00E+01
5.00E+00
0.00E+00
3.5
5.0
6.5
8.0
9.5
11.0
12.5
Theta (°)

FIG. 11

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US2004/019917

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G06K9/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G06K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)
EPO-Internal, WPI Data, INSPEC

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6 061 463 A (PHILLIPS NICHOLAS J ET AL) 9 May 2000 (2000-05-09) column 9, lines 13-42	25,27-31
A	the whole document	1-24,26, 32-124
A	US 4 544 267 A (SCHILLER MICHAEL) 1 October 1985 (1985-10-01) the whole document	1-124
A	US 6 341 028 B1 (BAHUGUNA RAMENDRA D ET AL) 22 January 2002 (2002-01-22) the whole document	1-124

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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°O° document referring to an oral disclosure, use, exhibition or other means

°P° document published prior to the international filing date but later than the priority date claimed

°T° later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

°X° document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

°Y° document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

°&° document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
5 November 2004	23/11/2004

Name and mailing address of the ISA	Authorized officer
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INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US2004/019917

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